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STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources
in cooperation with
Alameda County Water District

BULLETIN No. 118-1

EVALUATION OF GROUND WATER RESOURCES: SOUTH SAN FRANCISCO BAY

Volume II: ADDITIONAL FREMONT AREA STUDY

AUGUST 1973

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Secretary for Resources
The Resources Agency

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Governor
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Department of Water Resources

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The Bulletin No. 118 series, which is published by the Department of Water Resources for all interested agencies and the general public, includes:

Bulletin No. 118-1 <u>Evaluation of Ground Water Resources: South Bay</u>

Appendix A: Geology, August 1967

Volume I: Fremont Study Area, August 1968

Volume II: Additional Fremont Area Study,

Volume III: North Santa Clara County (now under study)

Bulletin No. 118-2 <u>Evaluation of Ground Water Resources: Livermore and Sunol Valleys</u> (now under study)

Appendix A: Geology, August 1966

After completion of the evaluation studies, operations-economics studies of each ground water basin or study area will be scheduled and conducted cooperatively with local agencies.

FOREWORD

The South Bay Ground Water Basin underlies south San Francisco Bay and the gently sloping lands adjacent to the Bay in Alameda, San Mateo, and Santa Clara counties. The ground water basin is divided into three main units: the Fremont study area, containing the Bay and southern Alameda County; the Santa Clara study area to the south; and the San Mateo study area to the west.

In the Fremont study area, extractions exceeded recharge for many years, resulting in extensive salt water intrusion of the ground water aquifers. The Alameda County Water District has countered the salt water intrusion by augmenting the ground water supplies of the Fremont study area with imported water supplies from the South Bay Aqueduct of the State Water Project and the City of San Francisco's Sunol Aqueduct. Withdrawals from the basin were also reduced by using imported water from the Hetch Hetchy Aqueduct.

This report is a supplement to Bulletin No. 118-1, "Evaluation of Ground Water Resources, South Bay, Volume I: Fremont Study Area", published in August 1968. The report presents the results of additional studies by the Department in cooperation with the Alameda County Water District, contains additional detailed geology of the area, and presents an accounting of recharge to and withdrawals from the ground water basin for the period October 1961 through September 1970.

During the period studied, actions of the local operating agency have resulted in a recovery of water levels in the ground water basin. However, the basin is still endangered by saline intrusion and preliminary design of a salt water barrier should be completed and construction started promptly. The conceptual plan for a salt water barrier is described in this report. Detailed planning for the barrier and testing of materials to be used for construction of the barrier are continuing as part of the cooperative study by the Department and the Alameda County Water District.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
July 25, 1973

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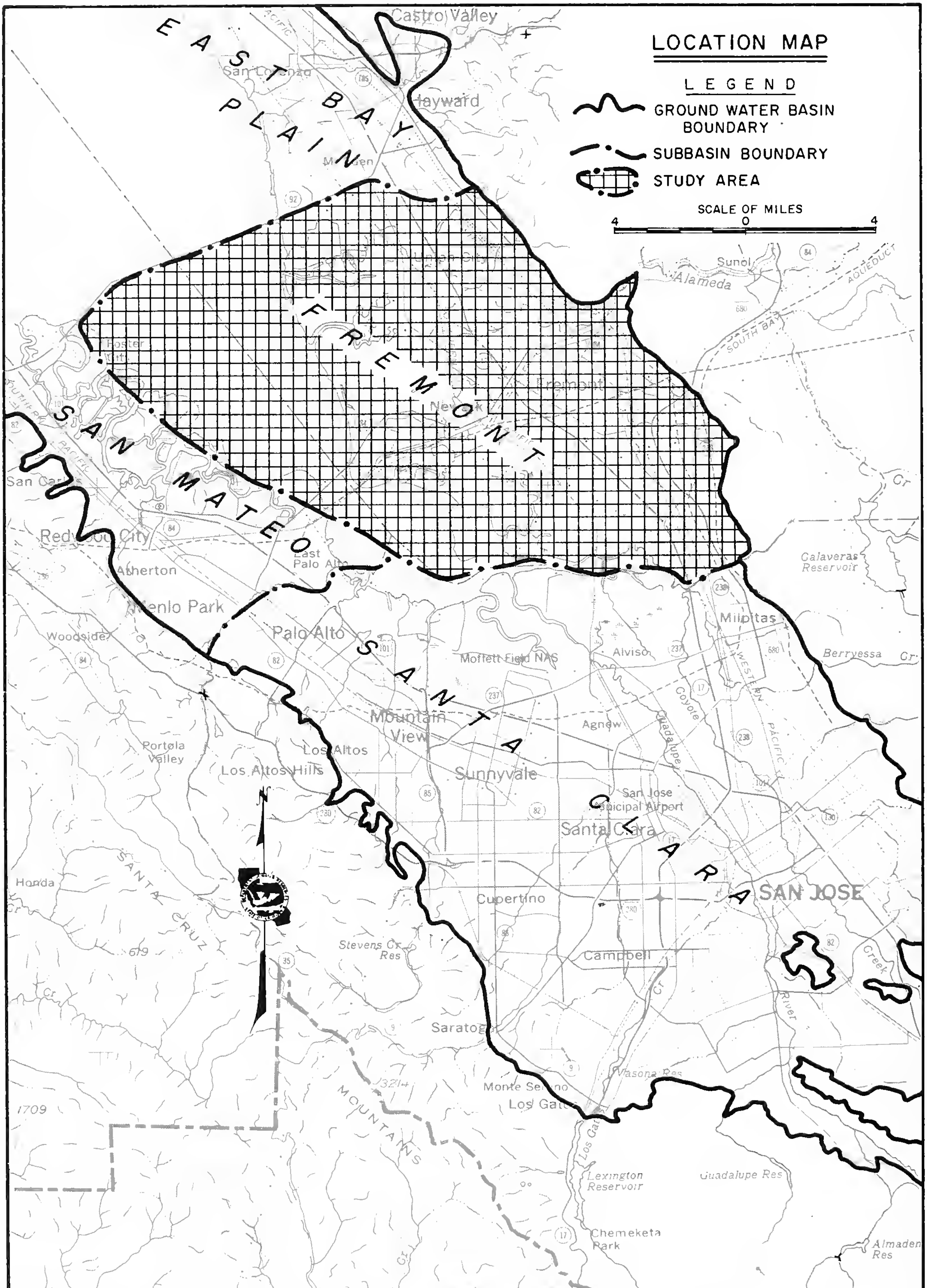
FIGURE 1


LOCATION MAP
LEGEND
GROUND WATER BASIN BOUNDARY
SUBBASIN BOUNDARY
STUDY AREA
SCALE OF MILES
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0
4
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FREMONT
SAN MATEO
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Newark
Foster City
San Carlos
Redwood City
Atherton
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CHAPTER I. SUMMARY, FINDINGS AND RECOMMENDATIONS

The Fremont study area, shown on Figure 1, is located in southwestern Alameda County and occupies the northeastern portion of the South San Francisco Bay ground water basin. From the 1920's to the present, saline water intrusion has been a problem in the area. The utility of the ground water reservoir has been preserved by the Alameda County Water District through the construction and operation of recharge facilities and the importation of water purchased from the State of California (State Water Project) and the City of San Francisco (Hetch Hetchy System).

Study Objectives

Detailed geologic and hydrologic studies of the Fremont area were made in the 1960's and the results published in two Department reports: Bulletin No. 118-1, "Evaluation of Ground Water Resources, South Bay, Volume I: Fremont Study Area", August 1968; and Appendix A, "Geology", August 1967. In June 1968, the Department and the Alameda County Water District entered into an agreement to study the ground water resource on a cooperative basis. The objectives of the study were:

1. Modification of the District's data collection program to provide greater areal coverage and increased reliability of data.

2. Further definition of the subsurface geology and hydrology of the ground water basin based on additional data obtained from the modification of data collection networks, drilling of test holes and pump testing.

3. Review of alternative methods of controlling saline water intrusion and the development of preliminary plans and costs for a proposed saline water barrier.

4. Development of criteria for use and operation of artificial recharge facilities.

Study Results

The cooperative study during the 1968-72 period has accomplished these objectives with the exception of the fourth, relating to the operation of the recharge facilities. The continuing construction of the new Alameda Creek flood control channel through the recharge facilities has forced this portion to be postponed, although the ground water model being developed during the study will assist in determining operational plans for the recharge facilities.

Modifications in the District's data collection program have been made during the study to take advantage of the more detailed information on the hydrology and subsurface geology of the ground water basin. The data collection program now

records changes in ground water levels and quality for each of the several aquifers and has been expanded to cover the entire study area.

The result of the geologic study is a detailed mapping of the subsurface channels of Alameda Creek and adjacent streams, and is presented in Chapter II as an extension of information presented in Volume I and Appendix A of Bulletin 118-1. The detailed mapping was accomplished by a new approach, utilizing computer methods to evaluate subsurface geologic data. This work is significant in that it provides the basis for the location and design of an efficient salinity barrier, and indicates that the subsurface flow of water is highly directional, an important input for the successful modeling of the basin. The model of the basin will be used in planning the salinity barrier. Understanding the separate roles played by aquifers and by aquitards in the ground water system is a necessary preliminary to controlling saline water intrusion. Aquifer and aquitard characteristics are described in Chapters II and III. Each of these can be defined as:

> Aquifer - A porous, water-bearing geologic formation. Generally restricted to materials capable of yielding an appreciable supply of water.
>
> Aquitard - A geologic formation which, although porous and capable of absorbing water slowly, will not transmit it rapidly enough to furnish an appreciable supply for a well or spring. The permeability is so low that for all practical purposes, water movement is severely restricted. When separating extensive aquifers having a large head differential between them, it acts as a confining bed but the total water movement may be significant even though water movement per acre is insignificant.

The results of the hydrologic studies are presented in Chapter IV as the status of saline water intrusion, and in Chapter V as an extension of the ground water inventory contained in Bulletin 118-1, Volume I, August 1968.

Review of alternative ways of controlling sea water intrusion indicated that a series of shallow pumping wells placed in the center of the subsurface channels defined in the geologic study could intercept saline water flowing into the basin and at the same time establish a bayward gradient in the intruded upper aquifer. This type of plan, called a pumping trough barrier, has been adopted as a basic plan. The preliminary location for the barrier reported on in Chapter IV uses the Coyote Hills as the central section and the eastern limits of the salt evaporation ponds as the north and south sections. As part of the continuing study, the District and Department have installed and tested one experimental well and are in the process of designing a second installation. Both agencies plan to continue developing a workable barrier design as rapidly as possible.

Findings

During the decade 1961-71, the amount of ground water in storage has been significantly increased by over 60,000 acre-feet and water levels have recovered approximately 55 feet in the forebay adjacent to the upper portion of Alameda Creek. During the same period average pumpage for beneficial uses has remained at approximately 40,000 acre-feet per year. Operation of gravel quarries during

the last three years of the study period involved pumping to lower water levels in the quarries. The water pumped by the quarries was wasted to San Francisco Bay. This practice was stopped in May 1971 by a Superior Court injunction obtained by the Alameda County Water District. The improvement in the ground water situation is primarily due to the importation and recharge by the Water District of large amounts of water through the State Water Project's South Bay Aqueduct.

The Alameda County Water District has plans to reduce the total pumpage for conventional uses from the basin for the next five years. An 8.0 million gallons per day water treatment plant to treat South Bay Aqueduct water for the District's distribution system is scheduled for completion in 1974, and this plant will be operated to reduce the District's pumping.

The District's full recharge capability has been used to meet pumping demands and to refill the ground water basin. By late 1972 the piezometric surface of the upper aquifer was at sea level. Recharge capability in excess of the requirements to maintain this level in the upper aquifer will be used to replace saline water that the District plans to pump from the basin. These plans are to pump saline water that is trapped in the Centerville, Fremont and deep aquifers into San Francisco Bay. If this saline water is not removed, it will spread to the usable parts of these aquifers and thus render them unusable.

It is important to complete preliminary design of a sea water barrier and to begin construction of a barrier. There are three compelling reasons for prompt action: (1) any decrease in the supply to or the operation of the recharge facilities can cause large amounts of salt water to intrude the basin; (2) uncontrolled migration of saline water from the upper intruded aquifer to the lower producing aquifers will continue to lessen the utility of the entire basin (initial operation of the barrier would withdraw saline water from the upper aquifer); and (3) the necessarily long construction time required to complete the barrier.

Recommendations

It is recommended that the planning of the sea water intrusion barrier and development and testing of prototype barrier wells, which are part of the current Department-District study, be completed as soon as possible so that the District can make a decision on starting a long range barrier construction program as rapidly as possible. Barrier wells should be designed and installed one or two at a time, tested, and results used to improve design of the next series of wells.

CHAPTER II. AQUIFER CHARACTERISTICS

The identification of horizontal and vertical boundaries of aquifers and aquitards is extremely difficult in most alluvial-filled valleys of California. In the past, this identification has been accomplished only on a gross scale and has been derived through the construction of geologic sections using drillers' logs of water wells as well as electric logs of oil and gas wells. Using this method, generalized formational boundaries and member boundaries can usually be determined. The subsurface data presented in Volume I of Bulletin 118-1, August 1968, and in Appendix A, August 1967, of that volume were derived in this manner.

This method of analysis does not provide the degree of detail that is required for operational studies of some ground water basins, particularly those in which older buried stream channels provide the media through which the major portion of ground water moves. Consequently, a new approach utilizing computer methods was developed to determine the continuity of the various aquifer systems present in the Fremont study area. In this approach, use was made of the now buried depositional patterns which make up the Niles Cone. In the construction of a depositional feature such as the Niles Cone, the contributing stream (in this case Alameda Creek) has meandered back and forth across the up to 12-mile width of the cone, depositing stream-borne materials which range in size from coarse gravel and boulders down to clay. During periods of normal runoff, a stream course is established which contains the coarsest grained materials. These materials grade from large gravels and boulders at the apex of the cone to sand and silt at its distal end. Adjacent to the stream channel are clays and silts which grade outward to even finer grained materials. Periodically, during periods of storm runoff, the stream will abandon its course and seek a new route down the surface of the fan. It also may meander over short distances of less than a thousand feet, thus forming braided channel deposits. In time, as deposition continues, the abandoned stream channels become covered with younger materials. These materials usually are fine grained, thus isolating the old stream channel and converting it into a tabular aquifer. In a few cases, younger stream channels may form along or across older channels, thus creating areas of hydraulic continuity between different channel deposits. In a few cases, the older, buried channels may subsequently become warped or cut off due to regional tilting or faulting.

Computer Assisted Subsurface Geologic Evaluation

In the Fremont study area, a special computer program was developed to utilize information on the subsurface materials derived principally from logs of water wells. In analyzing these logs, it was found that the "calls" used by various drillers differed for the same material. It also was found that drillers' calls may be grouped, and thus a statistical analysis may be made based on these calls. This same approach was used by the U. S. Geological Survey, which grouped the drillers' calls by specific yield values in its study of the San Joaquin Valley. This grouping of calls, modified for the Fremont study area, is

presented on Table 1. The steps in the geologic analysis which utilized this grouping are briefly described below.

1. The deepest well per quarter-quarter section (a one-quarter mile spacing) in the study area was identified and the values of the equivalent specific yield (ESY) tabulated for each material reported on the log. Equivalent specific yield is defined as being equal to the specific yield of a given material under unconfined conditions. The ESY of a material is a pure number and remains the same whether the material is presently under confined or unconfined conditions, as it relates to the relative grain size and not to the quantity of ground water which could be derived from it.

2. The ESY values were averaged for 10-foot increments of elevation for each well used.

3. The averaged ESY values were then converted to symbolic form for utilization in graphic presentation. Four symbols were used which represent the main types of depositional material:

Symbol	Range of ESY Values	Typical Material
.	1 to 7	Clay, Bay Mud, Silt
-	8 to 12	Clay with Fine Sand
+	13 to 17	Sand with Clay Streaks
0	18 to 25	Gravel, Coarse Sand

4. Using a computer program, the symbolic ESY values were printed out areally for each 10-foot increment of elevation at a horizontal scale of 1-inch equals 4,000 feet. Each of these "maps" were then printed on transparent media and prepared for viewing and analysis.

5. Geologic interpretation of the several maps was then made by stacking them in ascending order of elevation. In this case, maps of the Fremont area were made for the intervals of -550 to -540 feet up to +190 to +200 feet. By viewing the maps from above, the traces of the buried stream channels could be seen meandering down through the various levels. Also, areas of fine grained material could be identified as well as zones of hydraulic continuity between various levels.

6. It was recognized that several layers of clay, or aquitards, exist in the Fremont area, and it is believed that much of this material was deposited during times of a higher sea level. Thus it was concluded that zones of aqueously deposited clay could be identified and traced, as these clays are predominantly colored blue, green, or gray due to the reduced state of the iron present in the clays. In contrast, terrestrially deposited clays tend to contain iron in an oxidized state and thus are colored yellow, brown, or red.

TABLE 1

SPECIFIC YIELD VALUES
FOR DRILLERS CALLS

General Material Type and Specific Type	Drillers Calls		
Crystalline Bedrock Specific Yield = 00 Percent	Granite Lava	Hard Rock Rock	
Clay and Shale Specific Yield = 03 Percent	Adobe Boulders in Clay Cemented Clay Clay Clayey Loam Decomposed Shale	Granite Clay Hard Clay Hard Pan Hard Sandy Shale Hard Shell Muck Mud	Shale Shaley Clay Shell Rock Silty Clay Loam Soapstone Smearey Clay Sticky Clay
Clayey Sand and Silt Specific Yield = 05 Percent	Chalk Rock Clay and Gravel Clayey Sand Clayey Silt Conglomerate Decomposed Granite Gravelly Clay Lava Clay Loam	Peat Peat and Sand Pumice Stone Rotten Conglomerate Rotten Granite Sand and Clay Sand and Silt Sand Rock Sandstone	Sandy Clay Sandy Silt Sediment Shaley Gravel Silt Silty Clay Silty Loam Silty Sand Soil
Cemented or Tight Sand or Gravel Specific Yield = 10 Percent	Arcade Sand Black Blue Sand Caliche Cemented Boulders Cemented Gravel	Cemented Sand Cemented Sand and Gravel Dead Gravel Dead Sand Dirty Pack Sand Hard Gravel	Hard Sand Heavy Rocks Lava Sand Soft Sandstone Tight Boulders Tight Coarse Gravel Tight Sand
Gravel and Boulders Specific Yield = 15 Percent	Cobbles and Gravel Coarse Gravel Boulders Broken Rocks	Gravel and Boulders Heaving Gravel Heavy Gravel Large Gravel	Rocks Sand & Gravel, Silty Tight Fine Gravel Tight Medium Gravel Muddy Sand
Fine Sand Specific Yield = 15 Percent	Fine Sand	Quicksand	Sand, Gravel, and Boulders
Sand and Gravel Specific Yield = 20 Percent	Dry Gravel Loose Gravel	Gravelly Gravelly Sand Medium Gravel	Sand and Gravel Sand Water Gravel
Coarse Sand and Fine Gravel Specific Yield = 25 Percent	Coarse Sand	Fine Gravel	Medium Sand Sand and Pea Gravel

Based on Geological Survey Water Supply Paper 1469, "Ground Water Conditions and Storage Capacity in the San Joaquin Valley, California", 1959.

A separate computer program using the same well logs was developed to separate reduced and oxidized clays. The color of the materials was noted for each elevation increment and this information was put into a computer program which printed out the percent of reduced clay, ranging from 0 for a 10-foot thickness of oxidized clay to 99 for a like thickness of reduced clay. Using these data in conjunction with the ESY data, it was found that certain zones of the fine grained materials were composed principally of reduced clay and thus probably were deposited subaqueously. Because of this, it may be assumed that the subaqueous clays are fairly continuous and serve as aquitards.

Geologic sections which were prepared from well logs and the area printouts are presented as Figure 2. Figure 3 presents configurations of aquifer and aquitard materials at selected elevation intervals. Examination of the various maps and sections will show that the Fremont study area is roughly divisible into several aquifer zones and aquitards. From the ground surface downward, these zones, which are indicated on the geologic sections, are: Newark Aquitard, Newark Aquifer, Irvington Aquitard, Centerville Aquifer, Mission Aquitard, and Fremont Aquifer.

For interpretative purpose, materials have been separated into aquifer and aquitard groups on the basis of having average specific yield values of under or over 7 percent. The transmissibility of the aquifer materials increases generally with increasing specific yield, with a low transmissibility rate for specific yields near 8 percent.

Interpretation of the data uses average values for 10-foot elevation increments. As a result, the geologic sections may show aquifer or aquitard materials to be five feet thicker or thinner than the actual thickness. Surface exposures of aquifer material shown in the geologic sections should be interpreted as meaning that aquifer materials are present in the first ten feet of depth. This does not however, preclude the existence of extensive clay deposits of up to approximately seven feet thickness. In addition, the grain size of aquifer materials becomes finer with increased distance from the apex of the alluvial fan formed by Alameda Creek. This fan, called the Niles Cone, is the major physiographic feature of the Bay Plain portion of the Fremont study area. All of the aquifers and aquitards in this area are present as beds within this cone, as most of the materials were either derived from deposition by Alameda Creek or were influenced by it.

Sequences of Aquifers and Aquitards

The Newark aquitard is exposed at the ground surface throughout much of the Fremont area. This is the "clay cap" that is commonly spoken of by the various well drillers. The aquitard is composed of a mixture of fine material deposited subaqueously and on land, slopes gently bayward, and is expressed on Sheets 1 and 2 of Figure 3 as the open area southwest, west, and northwest of the large area of aquifer material near Niles. Because some of the aquitard was transected by stream channels, several isolated bands of channel deposits are shown crossing it.

Lying immediately below the Newark aquitard is the Newark aquifer, which shows its greatest expression on Sheet 3 of Figure 3, in the elevation interval -30 to -40 feet. Subsurface relationships of this aquifer are shown in the geologic

sections on Figure 2. A minimum of aquifer material is shown on Sheet 6 of Figure 3, representing the elevation interval of -120 to -130 feet. This is inferred to be the main zone of the Irvington Aquitard in the eastern portion of the Niles Cone, increasing in thickness to an interval of -120 to -160 feet in the portion of the Niles Cone southeasterly and northerly of the Coyote Hills. The eastern portion of the clay zone also contains stringers of channel material. The clay zone westerly of the Coyote Hills is primarily subaqueously deposited fine material. Below the Irvington Aquitard is the Centerville Aquifer which is depicted on the geologic sections shown in Figure 2. It attains its greatest expression in the interval from -180 to -190 feet, as shown on Sheet 8 of Figure 3.

Of major importance to the understanding of salt water intrusion and its control, are the locations of the subsurface channels connecting the Newark Aquifer with lands underlying the salt evaporation ponds and South San Francisco Bay. The locations of the subsurface channels connecting the various aquifers with the main recharge areas is important in planning recharge programs and in selecting well locations. The axes of the subsurface channels between elevations +30 and -70 are shown on Figure 3, Sheets 1-4.

INDEX TO GEOLOGIC SECTIONS

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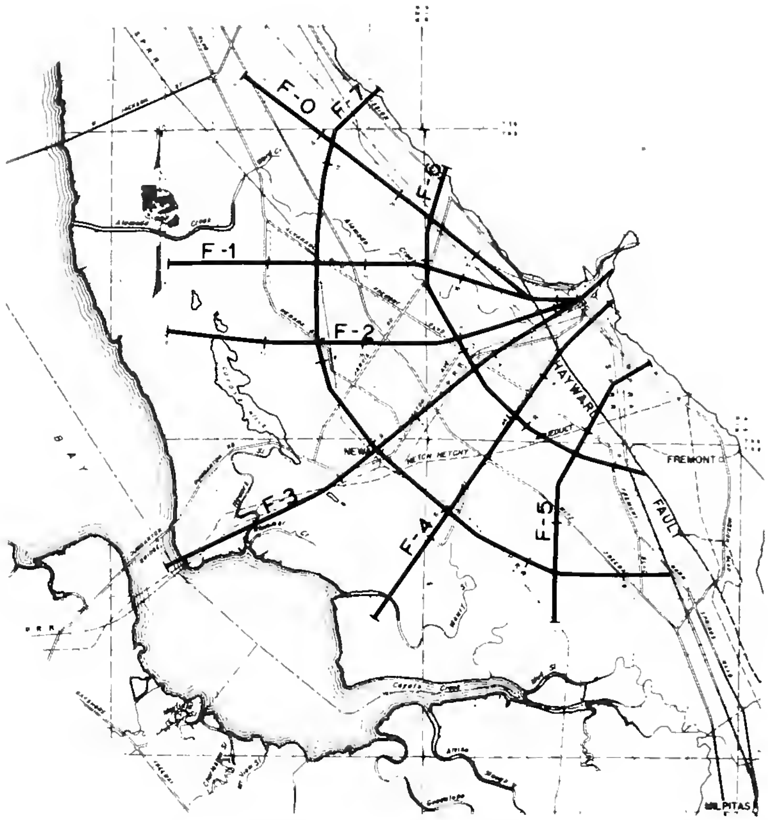
F-5, F-6	4
F-7	5



LEGEND

AQUIFER (MATERIALS HAVING SPECIFIC YIELDS GREATER THAN 7 PERCENT)

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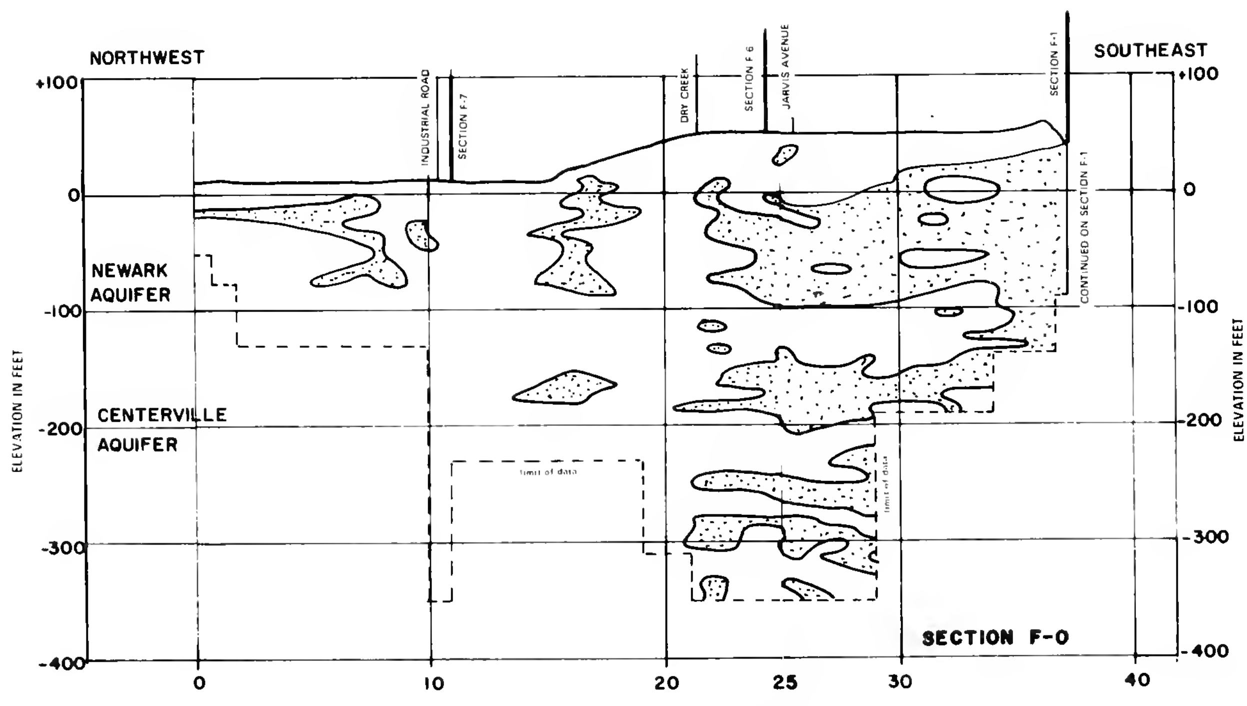
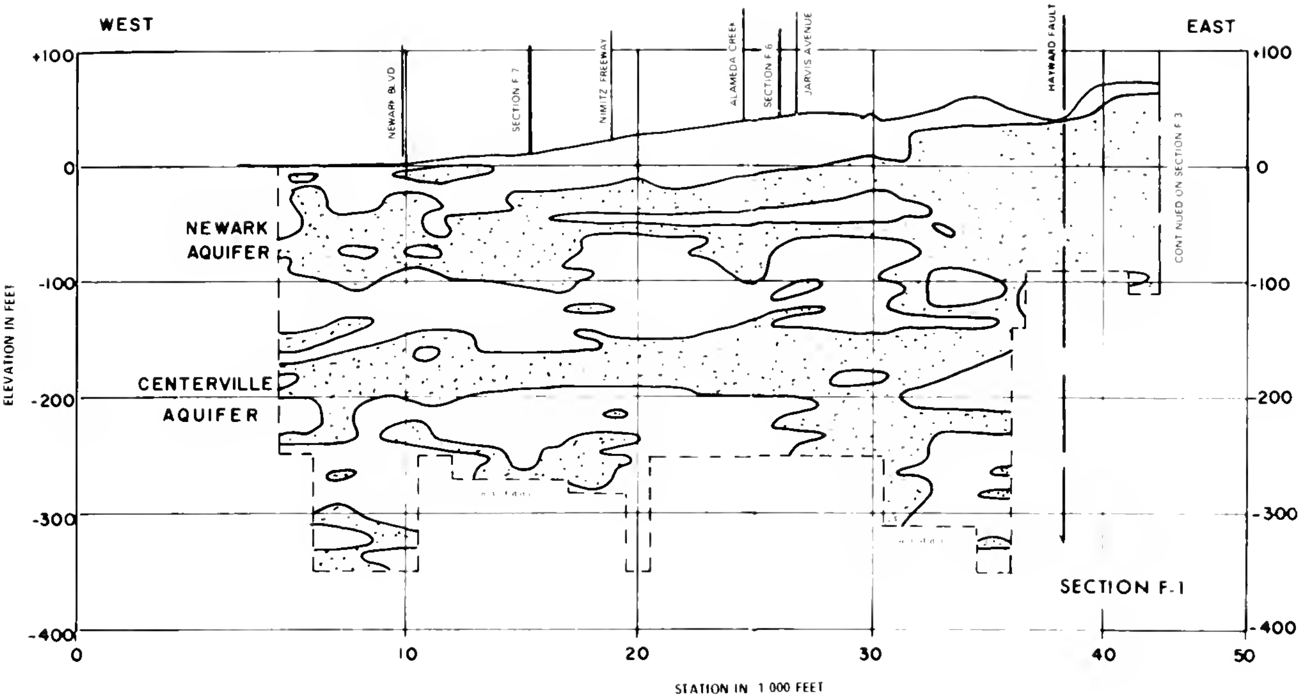


FIGURE 2 — GEOLOGIC SECTIONS



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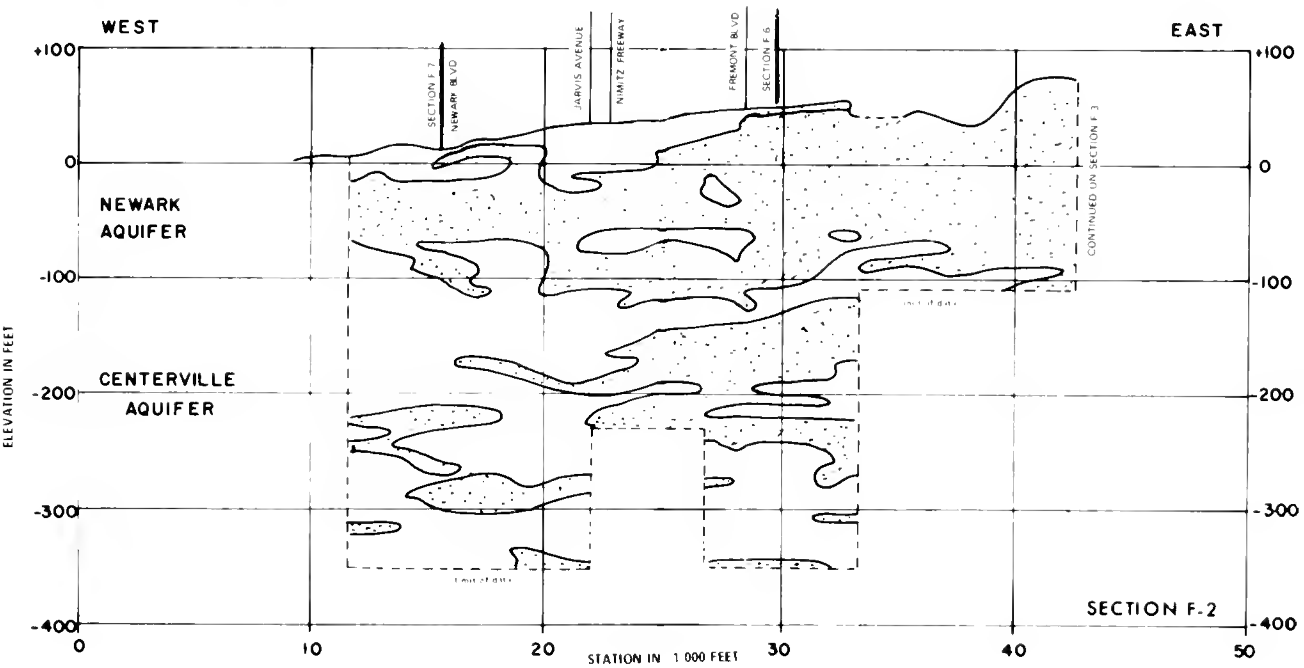
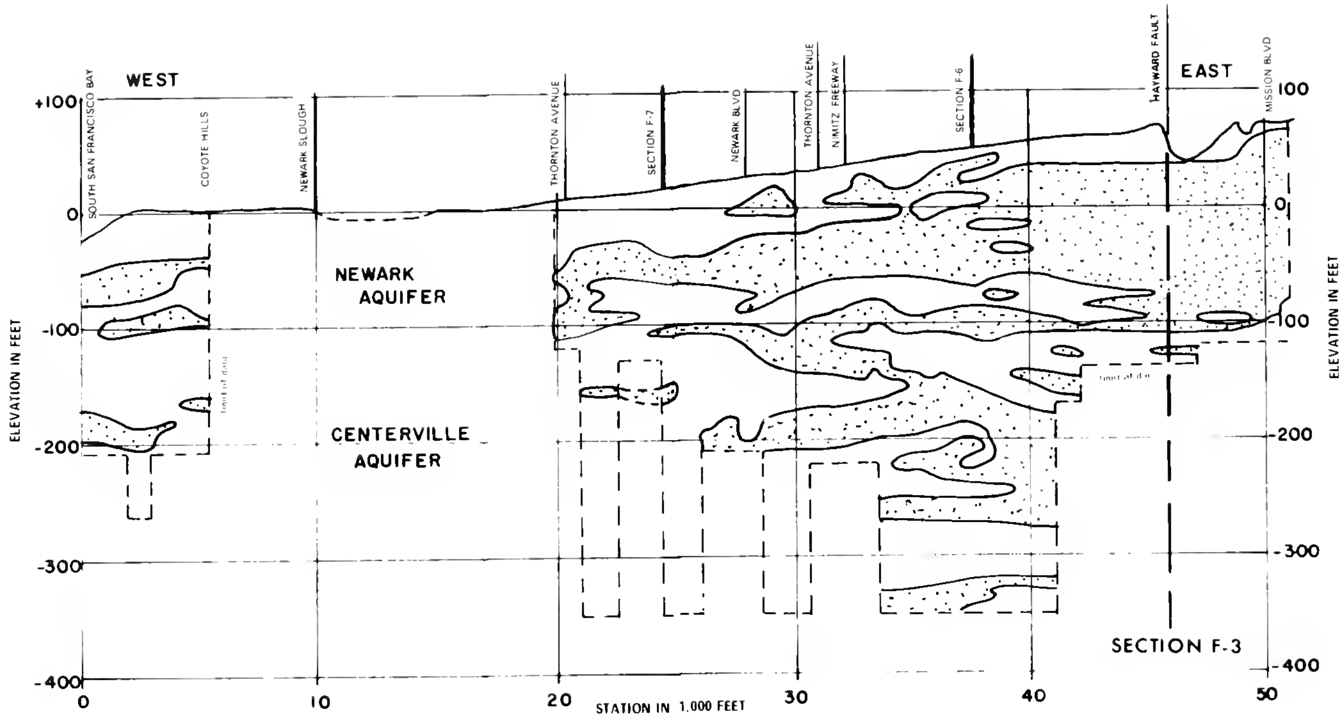
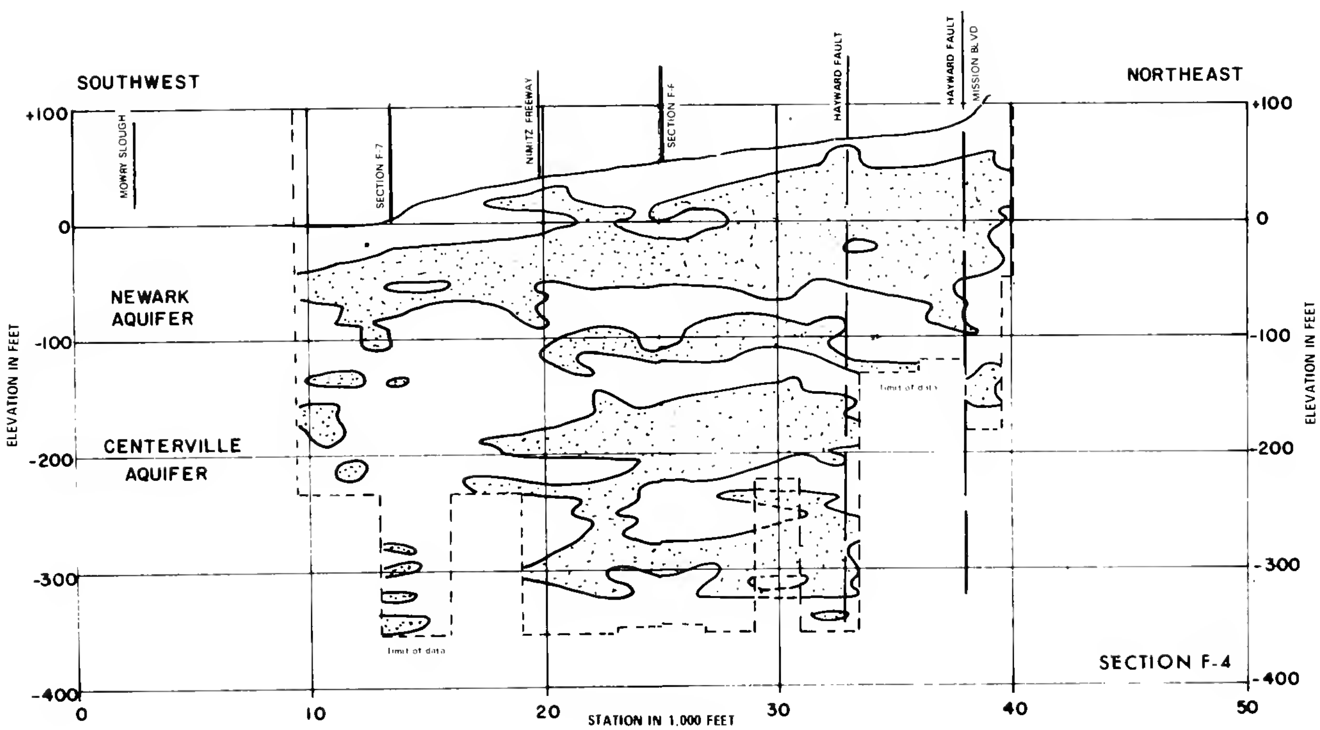


FIGURE 2 — GEOLOGIC SECTIONS

SHEET 2 of 5





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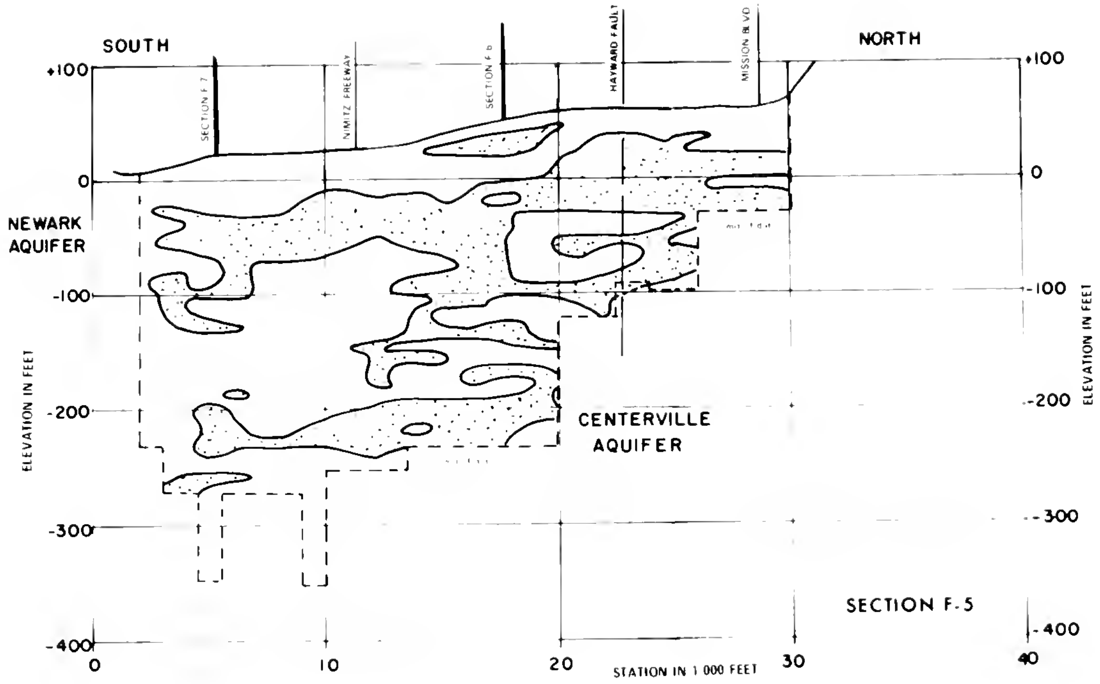

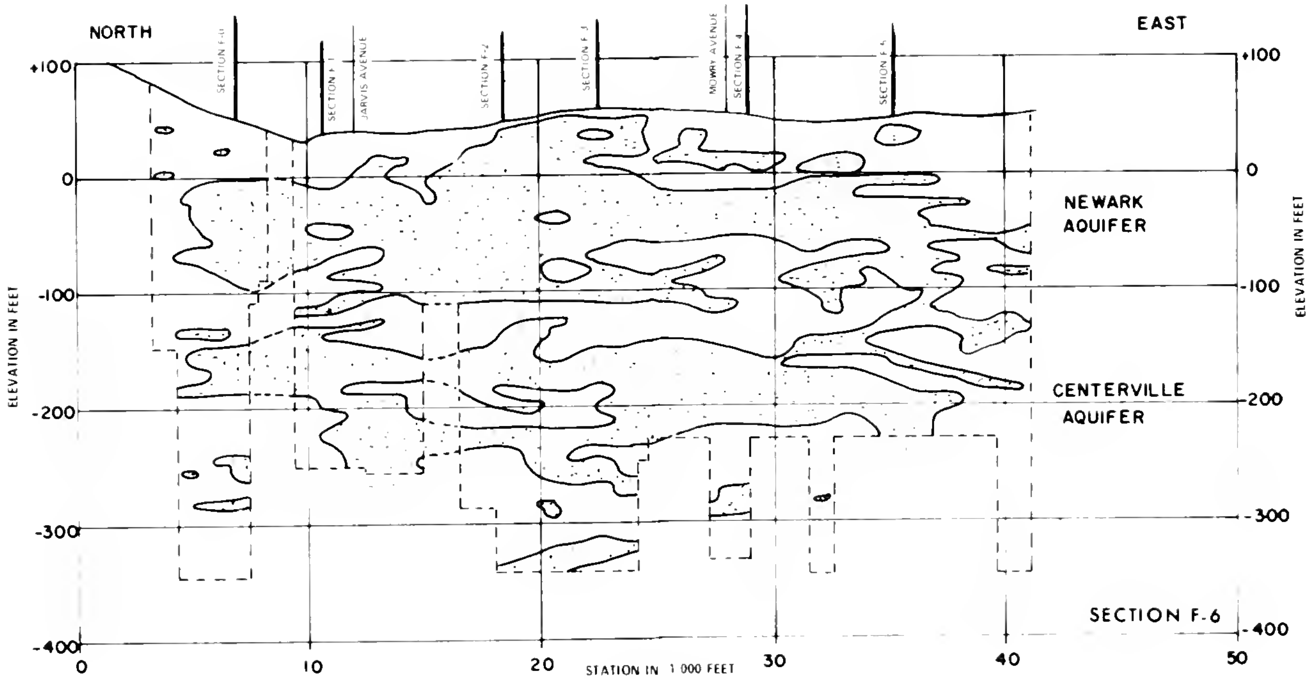

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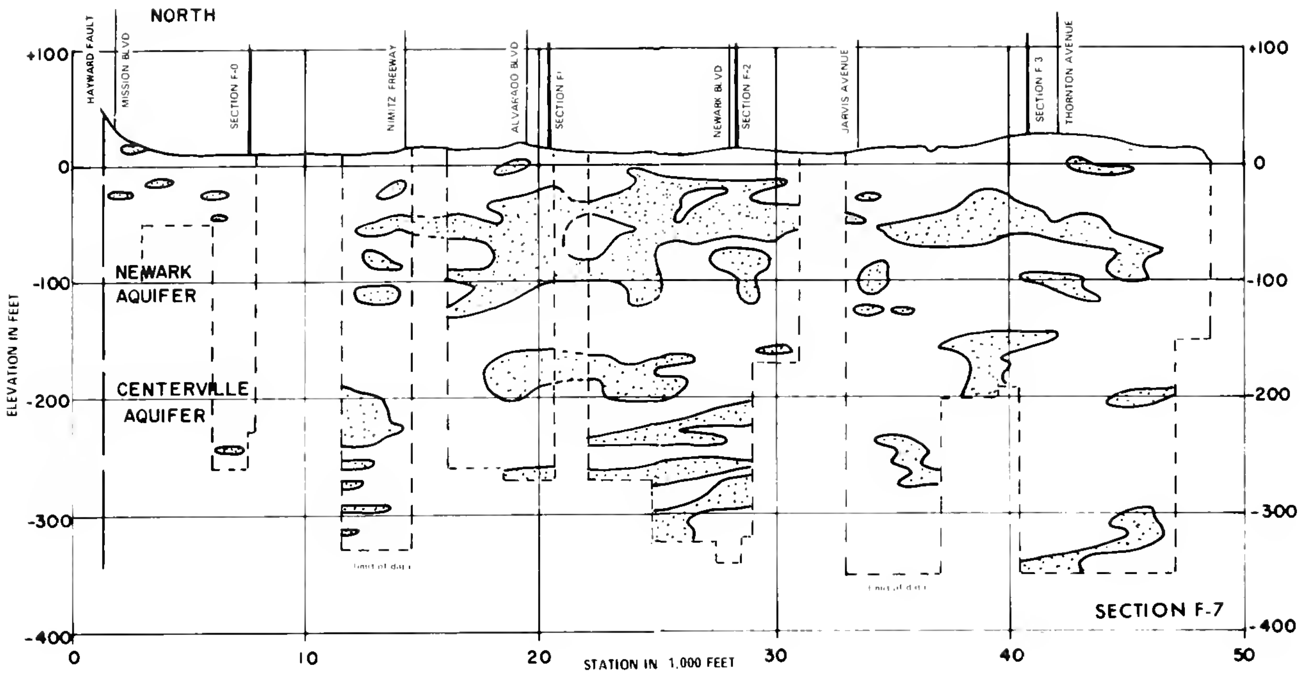

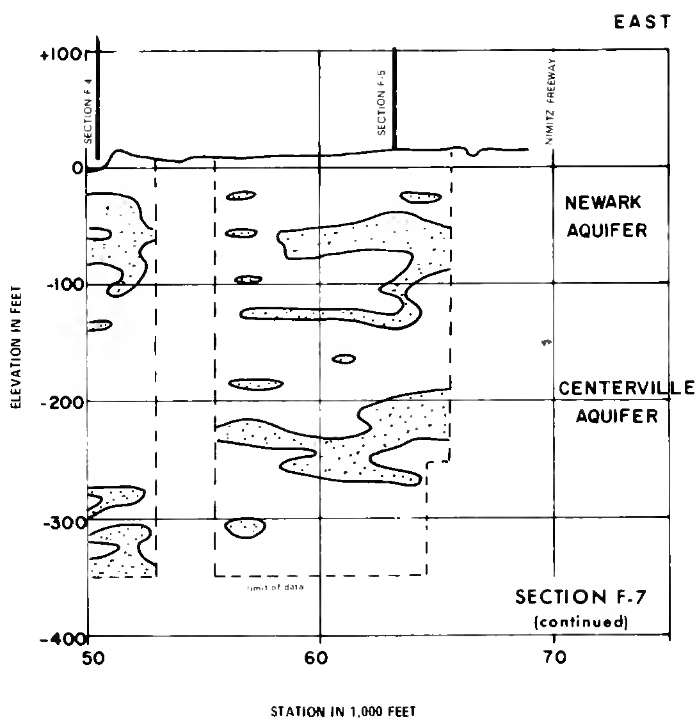

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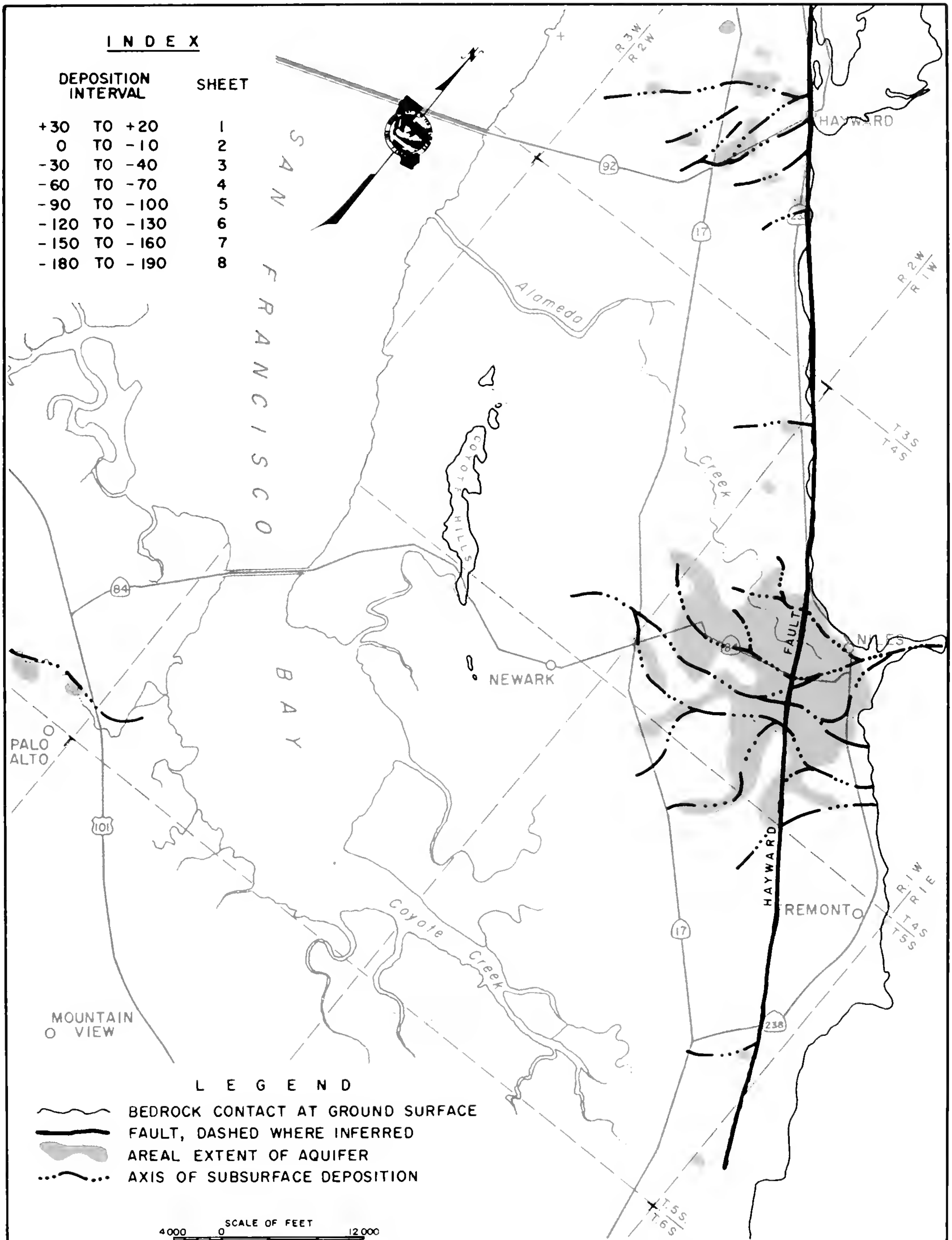


Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 1 OF 8 ELEVATION INTERVAL +30 FEET TO +20 FEET

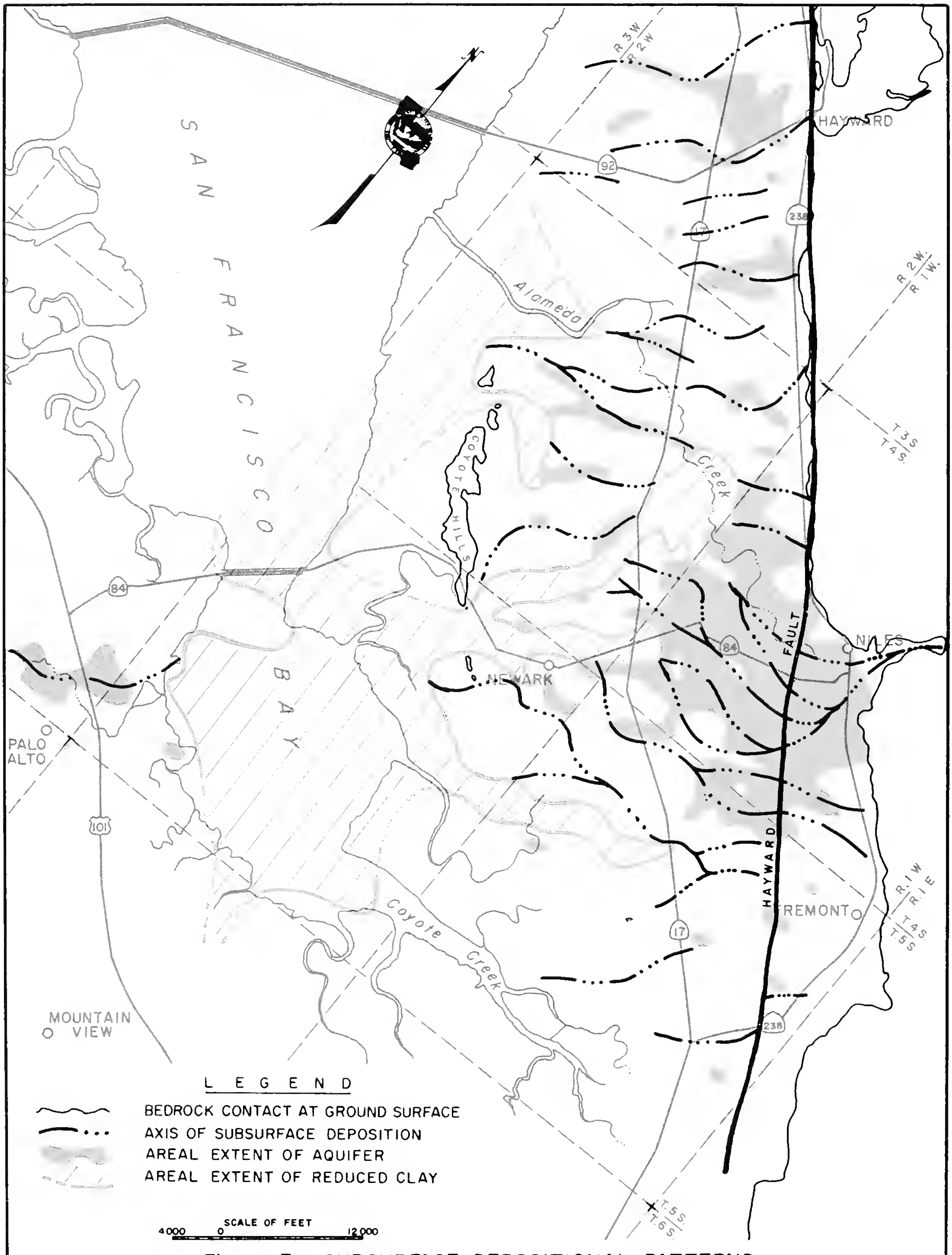


Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 2 OF 8 ELEVATION INTERVAL 0 FEET TO -10 FEET

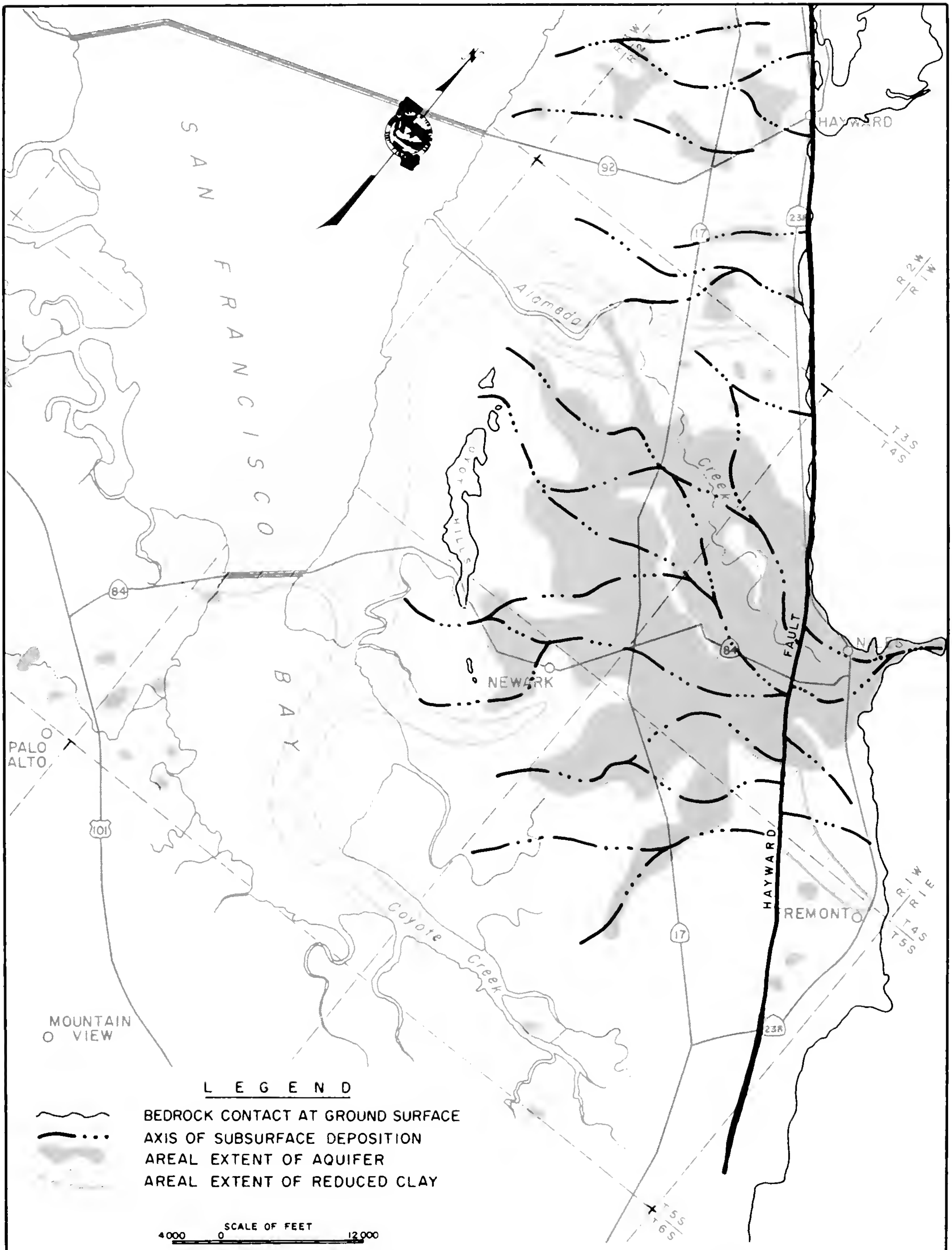


Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 3 OF 8 ELEVATION INTERVAL -30 FEET TO -40 FEET

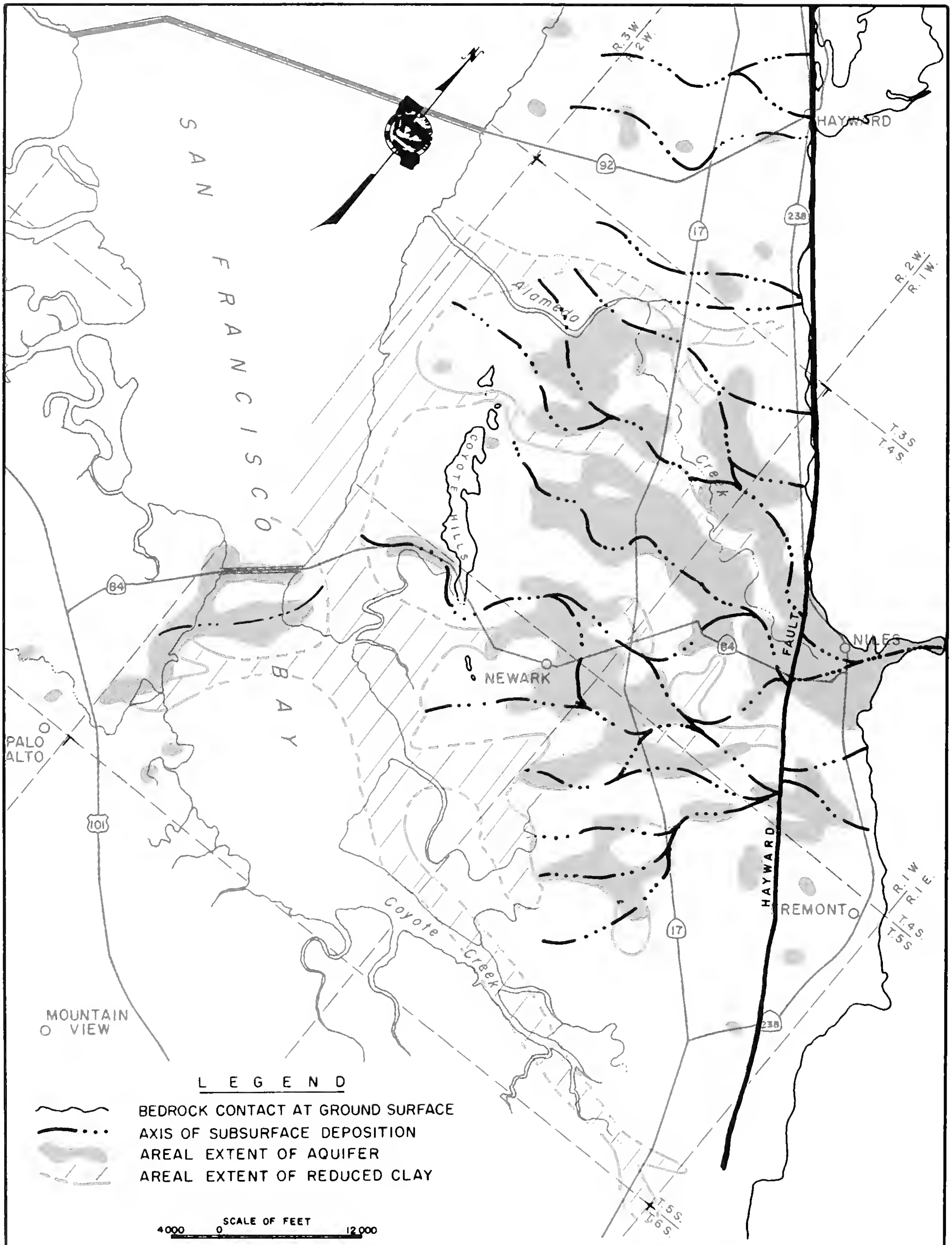


Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS

SHEET 4 OF 8 ELEVATION INTERVAL -60 FEET TO -70 FEET

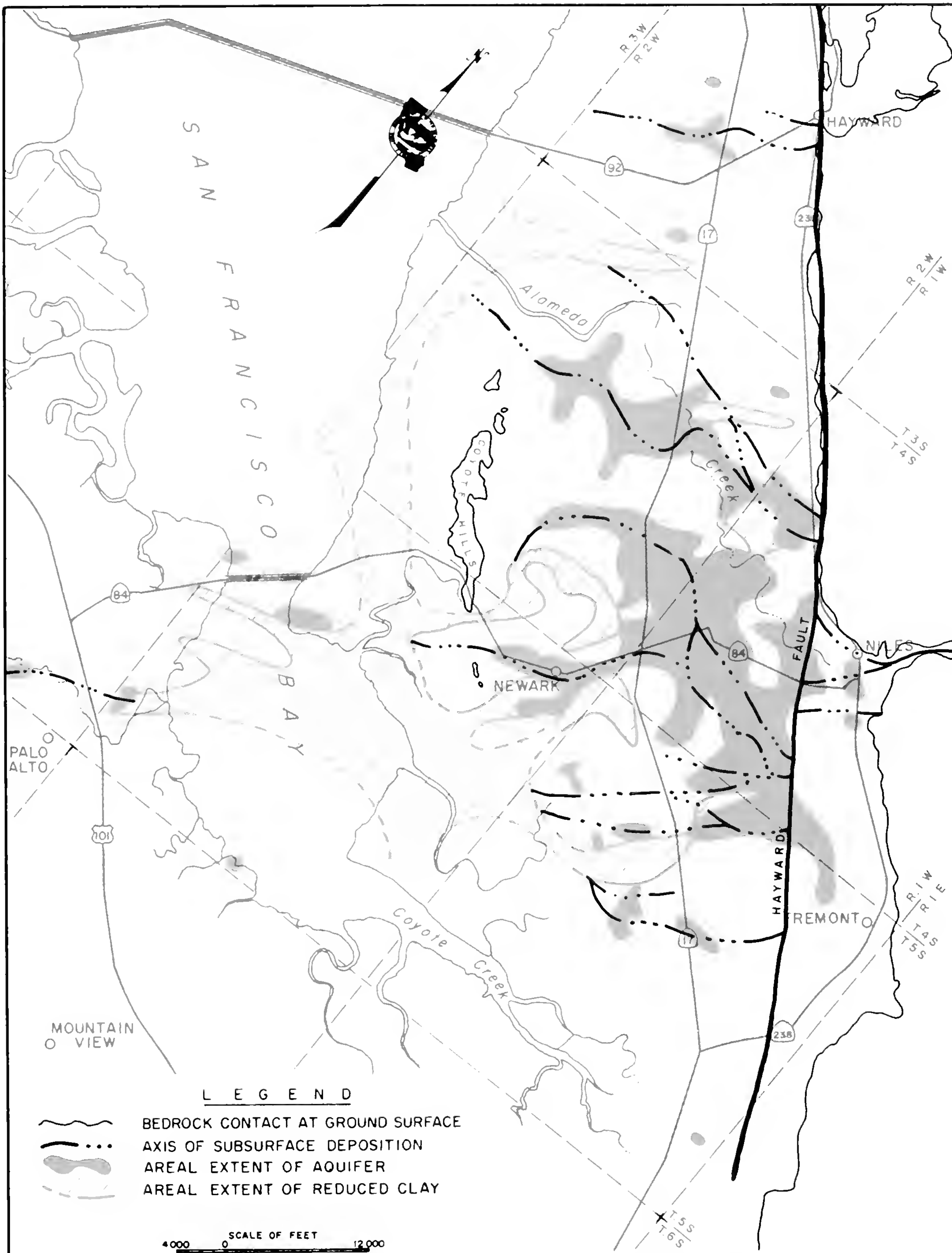


Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 5 OF 8 ELEVATION INTERVAL -90 FEET TO -100 FEET

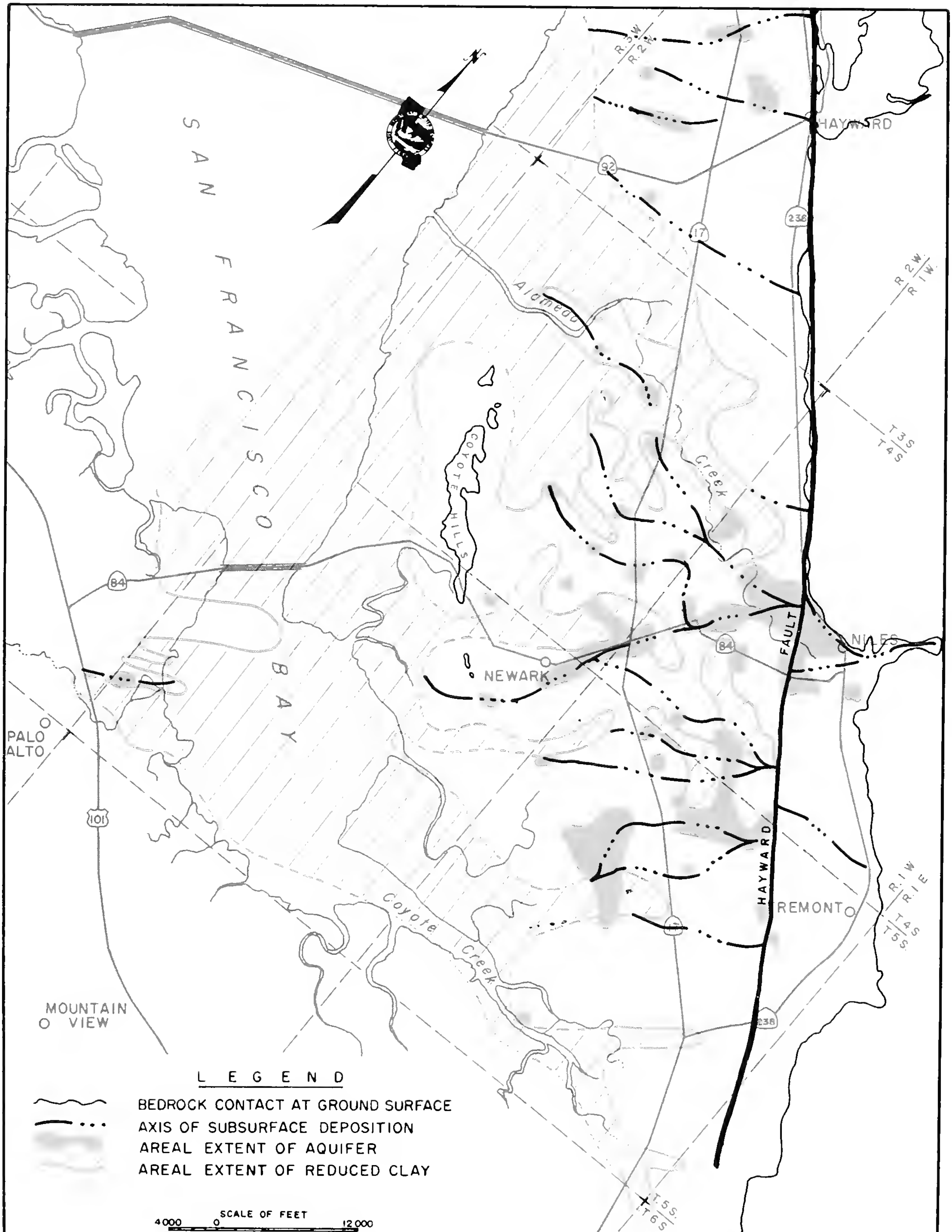


Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 6 OF 8 ELEVATION INTERVAL −120 FEET TO −130 FEET

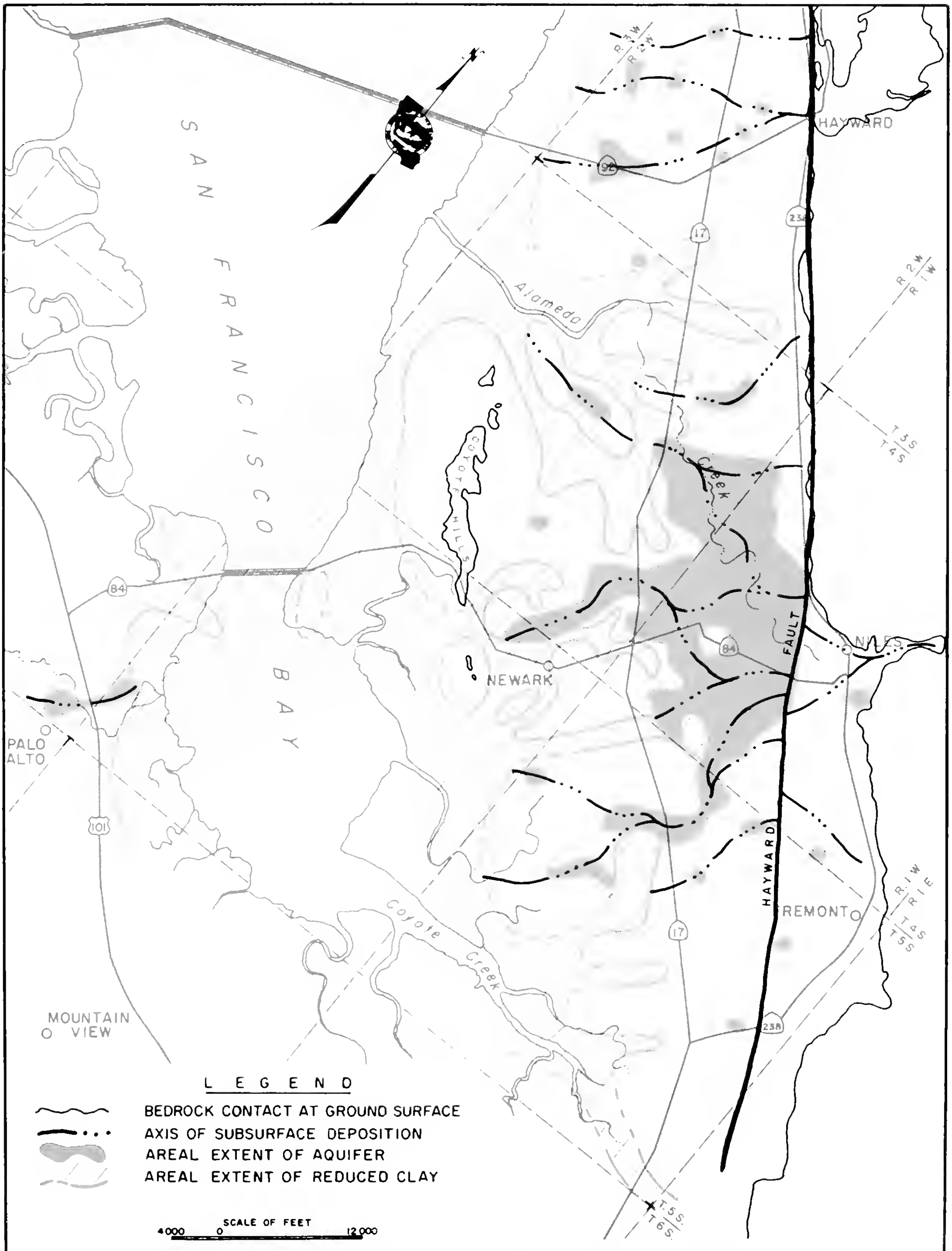


Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 7 OF 8 ELEVATION INTERVAL -150 FEET TO -160 FEET

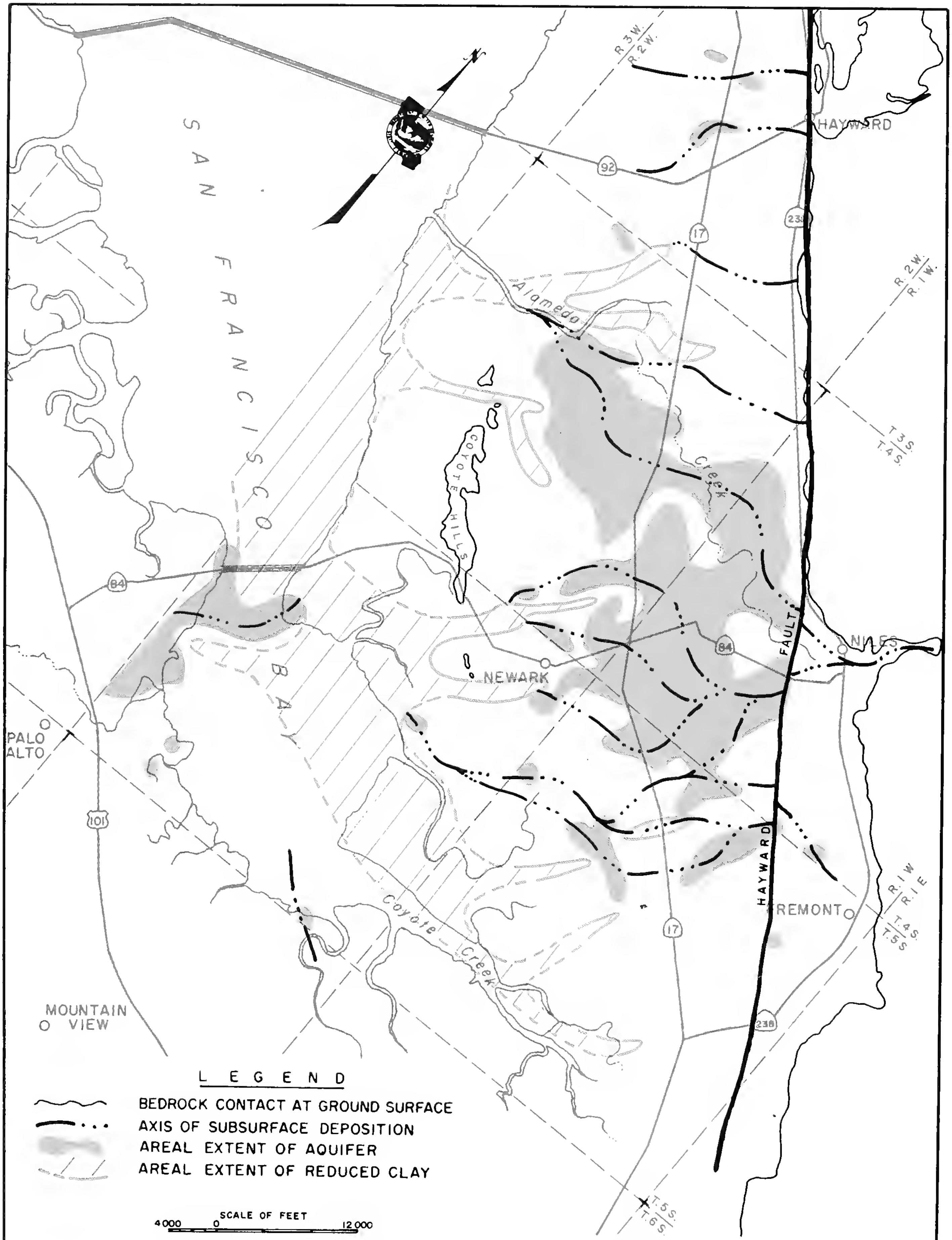


Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 8 OF 8 ELEVATION INTERVAL -180 FEET TO -190 FEET

CHAPTER III. AQUITARD CHARACTERISTICS

Nonsteady (fluctuating) flow of ground water to wells has traditionally been analyzed by considering each aquifer as an independent geologic and hydrologic unit. In the Fremont area at least three such aquifers exist, e.g., the Newark, Centerville, and Fremont Aquifers. Each of these aquifers is confined from above and below by layers that are of significantly less permeability. These layers, previously identified as aquicludes, have been found to possess definite permeability characteristics, to be compressible to some degree, and to release some water from storage. The descriptive term now applied to these confining beds is aquitards. Aquifers above or below the aquitards are termed leaky aquifers.

Because leakage suggests that there is some degree of hydraulic continuity between aquifers that are separated by an aquitard, the behavior of each aquifer is closely related to the behavior of the entire system. Hence, the group of aquifers and aquitards in the Fremont area should be considered as a multiple aquifer system rather than a group of individual aquifers.

Oxnard Plain Studies and Their Relationship to Fremont Area

Recent studies in the Oxnard area of Southern California sponsored by the Department of Water Resources and reported on in Bulletin 63-4, "Aquitards in the Coastal Ground Water Basin of Oxnard Plain, Ventura County", September 1971, indicate that aquitards play a very important role in the overall ground water systems of coastal ground water basins. The layering of aquitards and aquifers at Oxnard are analogous to those in the Fremont area and the role of the aquitards in both areas have similarities.

The aquitards in the Oxnard basin were found to have an average vertical permeability of about 10^{-6} cm/sec (0.02 gpd/ft^2). Bulletin 81, "Intrusion of Salt Water into Ground Water Basins of Southern Alameda County", December 1960, reported a vertical permeability value range of 0.002 to 0.016 gpd/ft^2 per foot of head for the Irvington Aquitard. Sensitivity analysis using the mathematical model of the Fremont study area made in 1967 indicated vertical permeability of the Irvington Aquitard separating the Newark and Centerville Aquifers (Figure 2) is in the 0.002 to 0.012 gpd/ft^2 range.

After giving consideration to distance from the apex of the depositional cones, the effect of the Coyote Hills and the depositional environment, it is estimated that the permeability of the Newark aquitard east of the Coyote Hills is at least 10^{-5} cm/sec (0.2 gpd/ft^2), while under the Bay it is assumed to be 10^{-6} cm/sec (0.02 gpd/ft^2). The permeability of the deeper Irvington aquitard is believed to be 10^{-7} cm/sec (0.002 gpd/ft^2). There are two reasons for the differences in permeability: (1) the clays in the Newark aquitard are composed of mixtures of

reduced and oxidized clays, while those in the Irvington aquitard are primarily reduced clays; and (2) the Newark aquitard includes more small subsurface channels than the Irvington aquitard. With an assumed permeability of 10^{-6} cm/sec (0.02 gpd/ft^2) for the Newark aquitard and under a unit gradient of 1 ft/ft, about 560,000 gpd, or 630 acre-feet per year, may move vertically across an aquitard having an area of one square mile. In the Fremont area, where there is a landward gradient in the Newark aquifer, it is possible for salt water from San Francisco Bay to enter the overlying aquifer zone, which crops out on the floor of the Bay. With a gradient of only 0.1 ft/ft, and a permeability of 10^{-6} cm/sec (0.02 gpd/ft^2) the amount of water that would pass through the aquitard underlying the Bay would be on the order of 60 acre-feet per year per square mile. Assuming that about 100 square miles of aquitard are overlain by saline waters, about 6,000 acre-feet of Bay water could move into the aquitard each year provided there is a downward hydraulic gradient.

With this amount of Bay water moving into the aquitard, the velocity of movement becomes of great importance, as this will set the time span for the water to pass through the aquitard and into the underlying aquifer. Assuming a vertical gradient of unity, and a permeability of 10^{-6} cm/sec, the Darcy velocity of water moving through the aquitard is one foot per year. Hence, in an aquitard which has a thickness of about 50 feet, and assuming a porosity of 50 percent, it would take about 25 years for water to pass through. However, if the vertical gradient is on the order of 0.1 ft/ft, the time factor is increased 10 times (25 to 250 years). If the thickness is only 10 feet, then under the latter conditions, it would take 50 years for salt water to move through it.

In addition to the movement of fluids through an aquitard due to purely hydraulic gradients, there is another force which may move ions through relatively impermeable materials. This is the chemico-osmotic diffusion of chloride ion through an aquitard which has a high concentration of chloride on one side and a low concentration on the other. This may be the case under two conditions in the Fremont study area. First, it may occur in areas where saline water overlies zones of good quality water in the Newark aquifer but is separated from it by the Newark aquitard. Second, it may occur at inland areas of intruded Newark aquifer which are underlain by lower aquitards and aquifers containing fresh ground water. In cases such as these, there is a coupling between solute concentration gradient ground water flow, i.e. the mechanism by which a salt concentration gradient causes ground water flow and a hydraulic gradient causes salt flow. This phenomenon is termed chemico-osmotic coupling.

In the studies at Oxnard, it was found that an aquitard which had a permeability of 10^{-7} cm/sec (0.002 gpd/ft^2) and separating a saline solution having 36,000 ppm chloride from fresh ground water, underwent definite chemico-osmotic diffusion. Curves developed from the study showed that if the aquitard had a thickness of 30 feet and there was no difference in piezometric heads above and below it, then it would take about 800 years for the chloride ion to diffuse through the aquitard. However, impressing a head differential of 10 feet toward the zone of fresh water reduced this travel time to 250 years.

The studies also showed that the rate of diffusion varies according to the square of the thickness of the aquitard. Hence, if the thickness of the aquitard was reduced from 30 to 10 feet, the 250-year travel time would be reduced to 30 years.

Furthermore, if the thickness was reduced to only one foot, the travel time would be very small, only 0.3 year.

Finally, the time required for the concentration of chloride ion to increase to 1,500 ppm in an underlying aquifer was computed at Oxnard for various thicknesses of aquitard, all at a hydraulic gradient of 1/3 ft/ft. With the 30-foot thick aquitard, it was found that it would take 1,050 years for the underlying aquifer to attain a concentration of 1,500 ppm chloride by chemico-osmotic diffusion. However, with a thickness of 10 feet, this time is reduced to 70 years, and with a thickness of only one foot, the time is further reduced to only 4 years.

Current Investigation

During 1971-72, a study of aquitard properties in the Fremont area was started under the guidance of Professor Paul A. Witherspoon of the University of California at Berkeley. Five shallow test holes were drilled using augers of different types and sizes, depending upon depth and type of material to be drilled. The locations of the test holes are shown on Figure 4.

During the drilling each change in lithology with depth was recorded, as well as a description of the material recovered. For each foot of hole drilled, a sample between three inches and one foot long was recovered from the auger. Care was taken to prevent contamination of the recovered cores from fresh water used in cleaning the auger or from surface soil and dust. The core sample immediately was placed into a labeled glass jar which was tightly capped. The samples obtained during a day's work were put in plastic bags and kept in the humidity room until the laboratory work could be done. The samples thus obtained are considered to be basically "undisturbed" and at field water content. During the laboratory procedures, care was taken to prevent evaporation.

Each of the core samples was divided into two parts. One was used to determine the water content of the soil; the other was used for the actual determination of the pore fluid salt concentration. Laboratory work was done at 20°C, and the results were adjusted to standard resistivities at 25°C.

The quantity of soluble salts (equivalent NaCl) in the pore fluid of the Newark aquitard materials, as estimated for several samples in each test hole, is presented in Figure 4 as graphs of depth in feet versus total dissolved solids in parts per million. The maximum values of salt concentration for each test hole are shown in Table 2.

There is a striking difference between the maximum salt concentrations of samples from test holes that are not in the area of salt ponds (but less than a mile away) and those that are directly in the area of salt ponds. The first two have a maximum salt concentration in the range of 2,500 ppm to 3,800 ppm (Test Holes A and B, Table 2), whereas the ones in the area of salt ponds (Test Holes C, D, and E) have salt concentrations that range from 17,500 to 60,000 ppm. The high values indicate that salt water has thoroughly invaded the aquitard layers. Fresh water is generally considered to contain less than 900 ppm

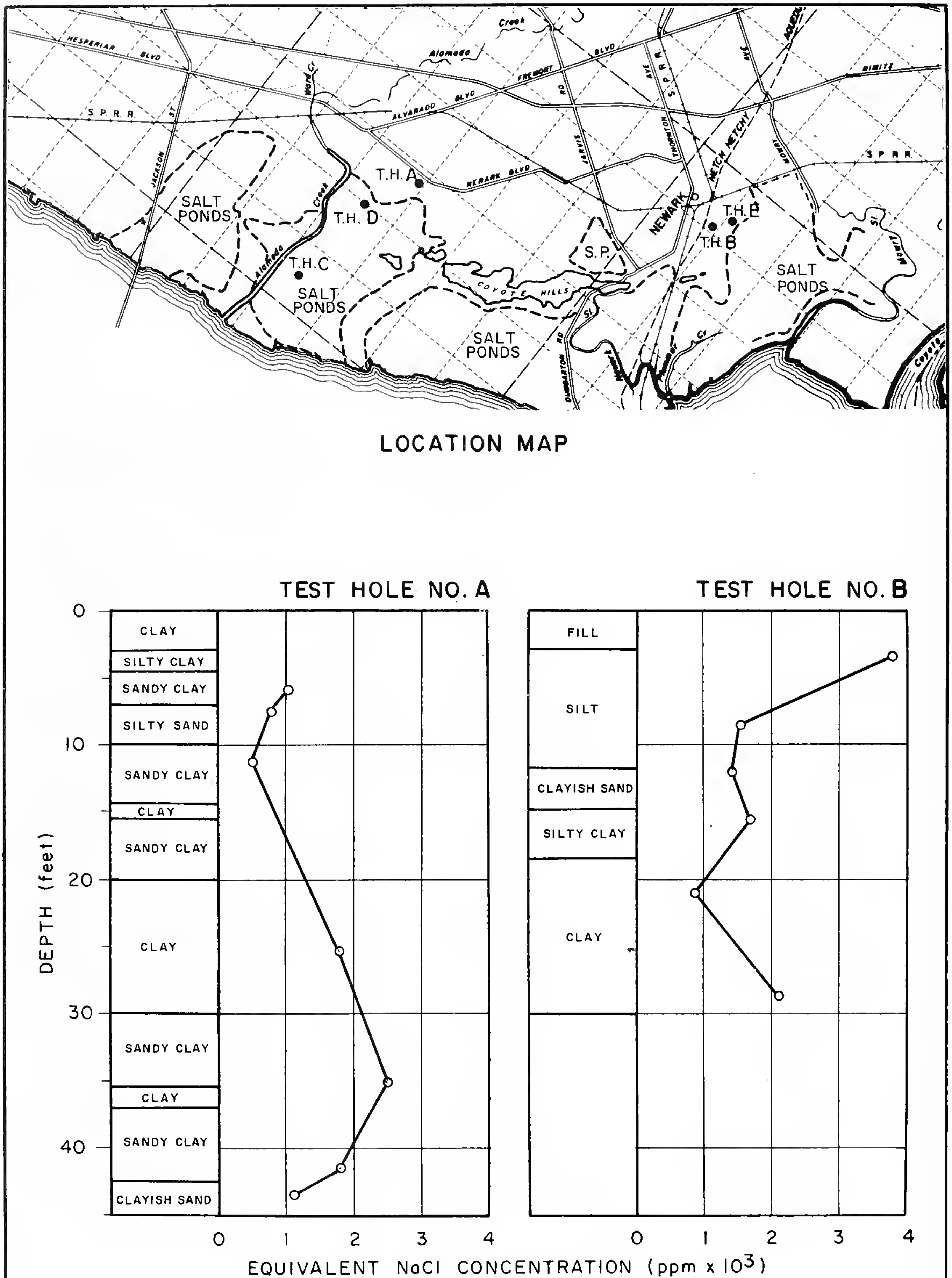


FIGURE 4: SALT CONCENTRATIONS IN NEWARK AQUITARD

SHEET 1 OF 2

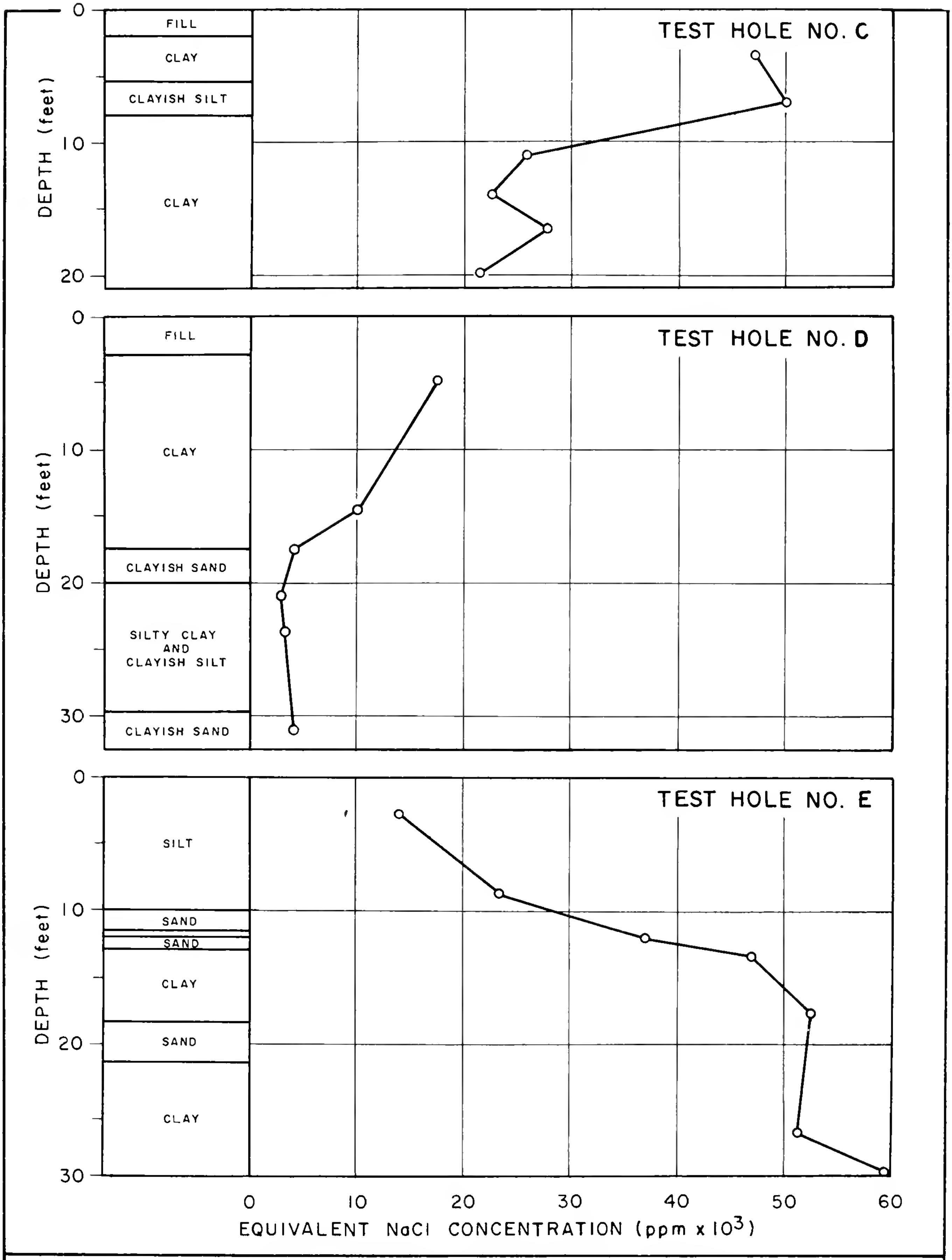


FIGURE 4: SALT CONCENTRATIONS IN NEWARK AQUITARD
SHEET 2 OF 2

chloride ion; ocean water approximately 19,000 ppm; South Bay waters range from 11,000 to 18,000 ppm; and salt evaporation ponds up to 215,000 ppm.

It appears that since some of the salt concentrations in the aquitard exceed the salt concentration in the South Bay waters, salt pond waters may constitute a source of degradation of the underlying aquifers. The mechanism for this salt water migration may be the result of a combination of two factors: chemico-osmotic diffusion, and a hydraulic gradient.

TABLE 2

SALT CONCENTRATIONS IN AQUITARD PORE WATER

Test Hole No.*	Location	Maximum Salt** Concentration (ppm)	Formation	
			Type	Depth (feet)
A	Outside Salt Pond	2,500	Sandy Clay	34
B	Outside Salt Pond	3,800	Silt	3
C	In Salt Pond	50,000	Silt	7
D	In Salt Pond	17,500	Clay	10
E	Adjacent Salt Pond	60,000	Clay	30

* Locations shown on Figure 4.
** Equivalent NaCl concentration.

CHAPTER IV. SALINE WATER INTRUSION, STATUS AND CONTROL

Intrusion of saline water into the portion of the ground water area north of the Coyote Hills was evident by 1924. Degradation continued and ground water in the shallow, or upper, Newark aquifer became progressively more unsuitable for irrigation use. The ranchers, in their search for suitable irrigation supplies, drilled wells deeper into the second, or Centerville aquifer, which is separated from the Newark aquifer by a nearly impermeable clay layer. Fresh water from deeper aquifers relieved the immediate problems, and the extent of the intrusion of saline water was not fully realized until 1950, when degraded water first began to appear in the Centerville aquifer. The salinity was first noticed in the Alvarado-Newark-Centerville area, and spread over a larger area.

Degradation of ground water by intrusion of saline water is probably caused by a combination of a number of conditions. The Newark aquifer is not in direct contact with San Francisco Bay except for localized areas where tidal currents or dredging may have scoured the bay mud and exposed the aquifer. Saline water may be entering the aquifer through openings in the bay mud and the clay cap, both of which overlie the aquifer, or the clay cap may have been breached by abandoned, unsealed wells.

Intrusion is caused by saline water from the bay and salt ponds flowing through breaks in the clay cap and the clay cap itself and into the Newark aquifer, under the pressure differential existing between the bay surface and the aquifer. Although the downward flow of salt water per square foot of area is very small, the annual amounts over the total area of bay and salt ponds can be large.

The hydraulic conditions allowing saline water intrusion and the paths of intrusion are shown on Figure 5. Pumping from the Centerville and deeper aquifers created a hydraulic depression, or trough, in the water levels east of the Bay. Thus the hydraulic gradient in these aquifers is bayward from the forebay and landward from the bay. The forebay is connected to all of the aquifers and receives recharge from the surface. The hydraulic gradient in the Newark aquifer during periods of intrusion is landward from the bay to the forebay.

Under these hydraulic conditions, saline water enters the portion of the Newark aquifer under the bay and the salt ponds. It then moves landward toward the forebay, and enters the lower aquifers by way of the forebay or by passing through the thin clay layers near the forebay. After the saline water has entered a lower aquifer, it then moves bayward down the hydraulic gradient toward the pumping depression.

Extent of Saline Intrusion

Figure 6 depicts lines of equal elevation of ground water and the status of salt water intrusion by isochlors (lines of equal chloride concentration in the ground water) in the Newark and Centerville-Fremont aquifers in the spring of 1970. The

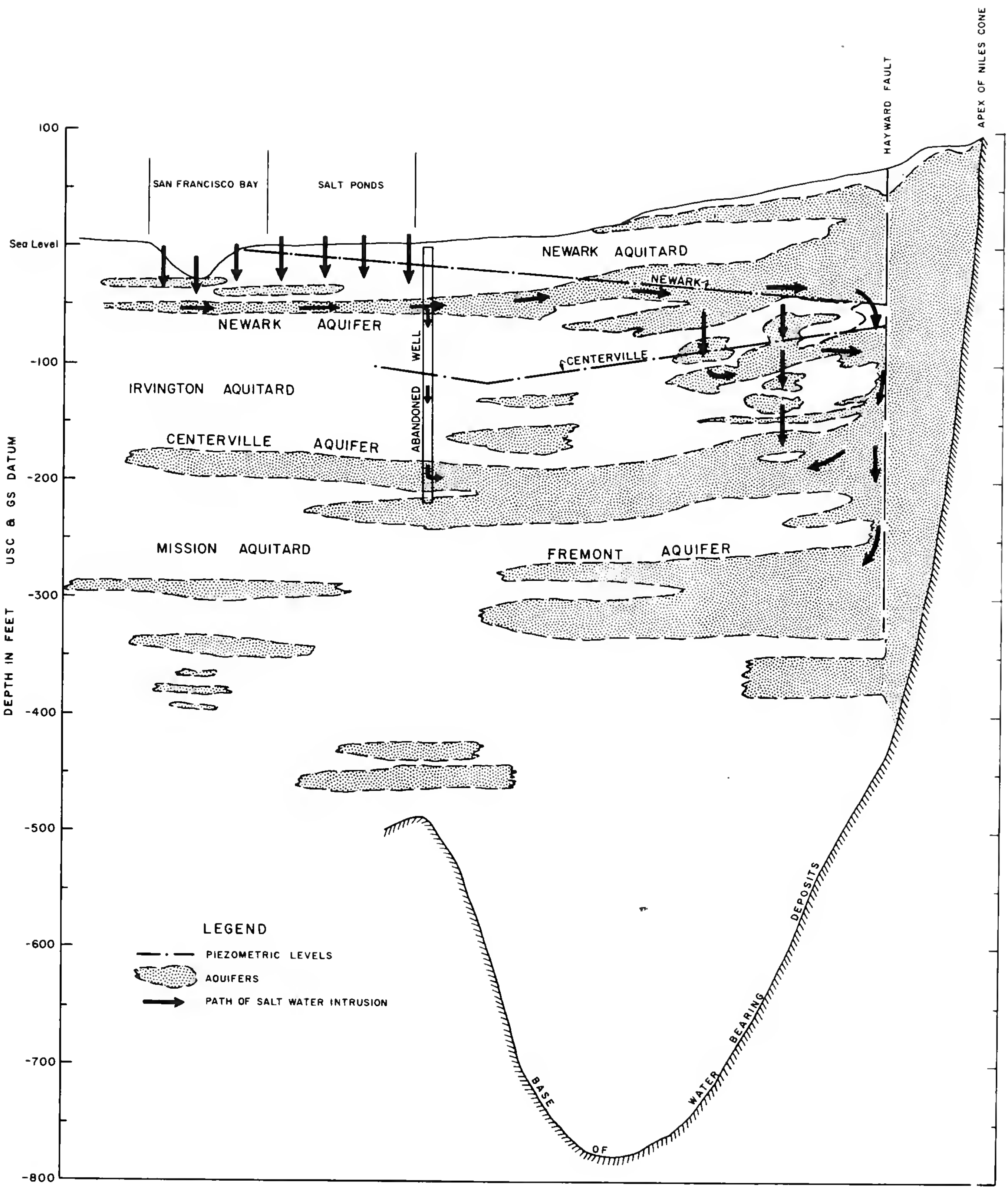
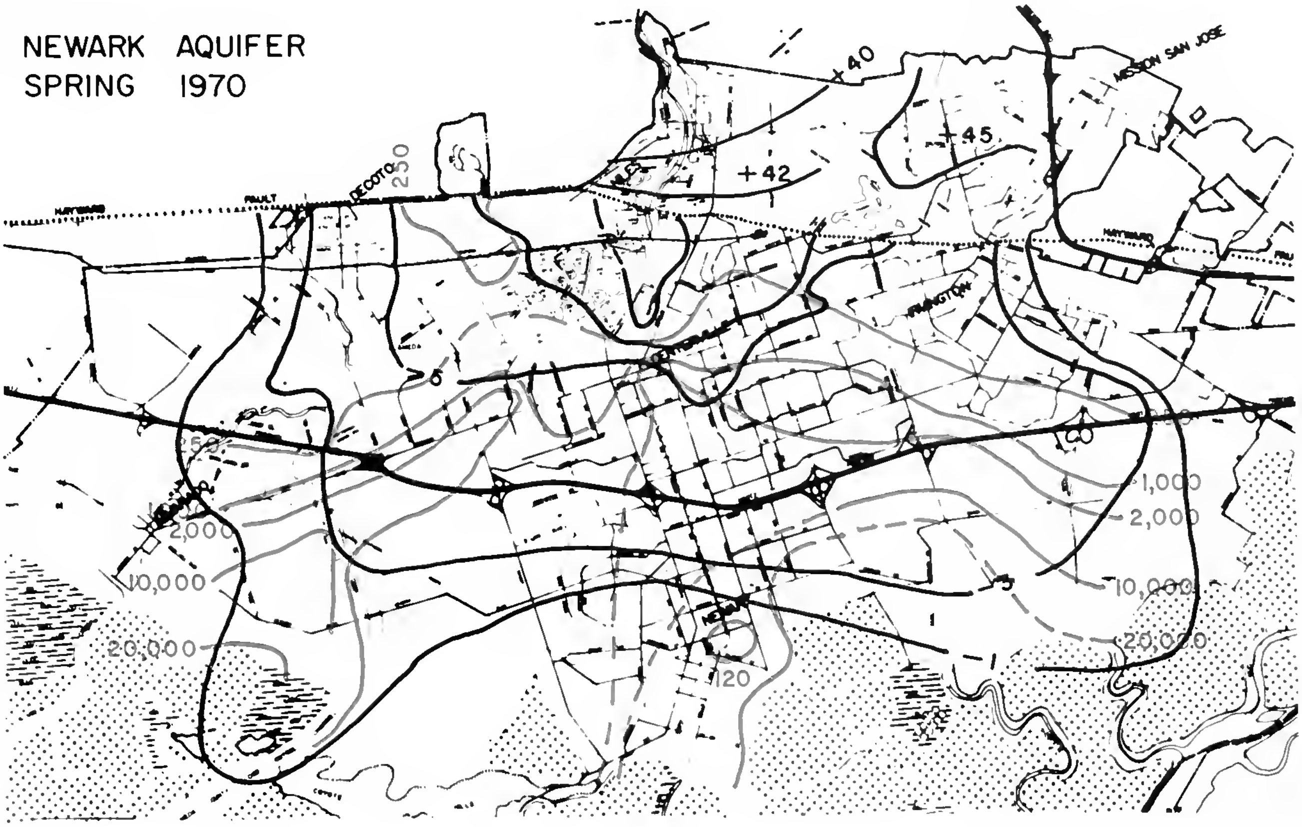


Figure 5. INTRUSION OF SALT WATER INTO THE FREMONT STUDY AREA (SCHEMATIC)



LEGEND

LINES OF EQUAL ELEVATION OF GROUND WATER IN FEET +40

LINES OF EQUAL CHLORIDE CONCENTRATION IN PPM 250 PPM

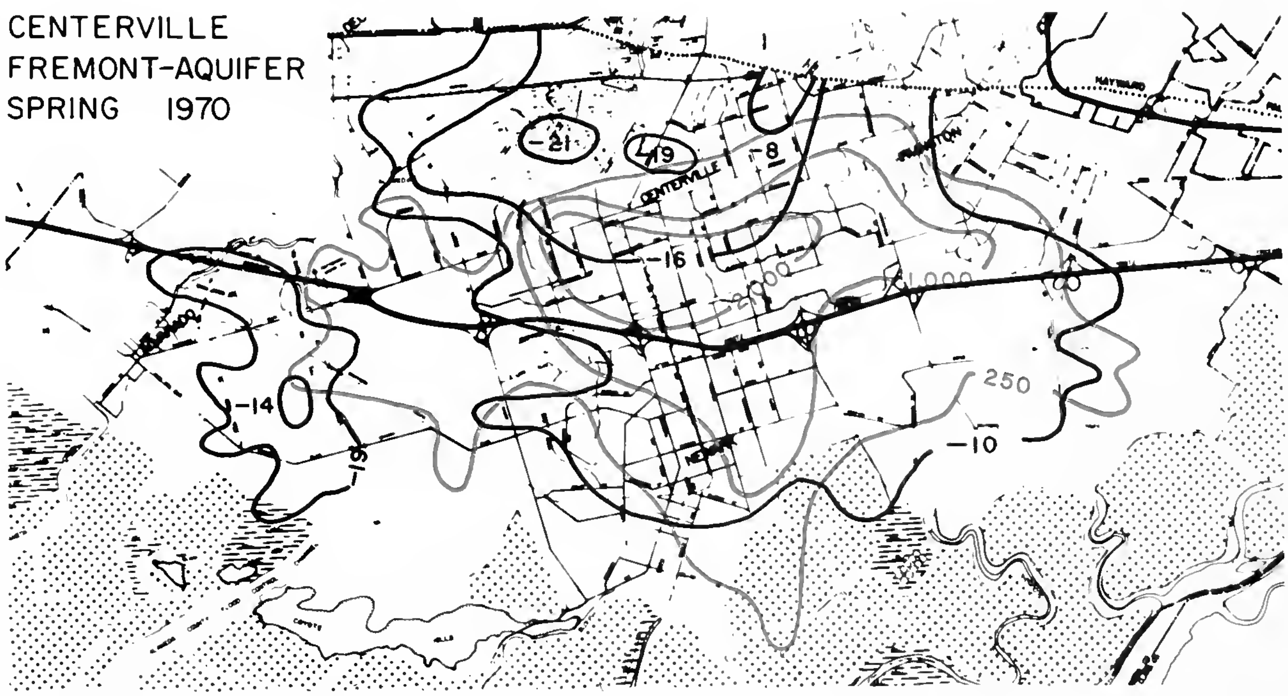


FIGURE 6 : GROUND WATER CONTOURS AND ISOCHLORS

figures should be considered as a graphic display of chloride concentration distribution rather than an exact comparison because the number of control points used and their locations are not constant.

The area of the Newark aquifer with salt concentrations in excess of 250 ppm chloride decreased about 600 acres from approximately 21,100 acres in 1963 to about 20,500 acres in 1972. The area of the Centerville-Fremont aquifer with salt concentrations greater than 250 ppm chloride increased about 3,000 acres from approximately 8,800 acres in 1963 to approximately 11,800 acres in 1972.

Volume of Saline Intrusion

To determine the total volume of intrusion which has taken place, it is necessary to assign an average salinity to the intruding waters. The two sources of intrusion are: the Bay, with salinities varying between 10,600 and 18,900 ppm; and the salt evaporation ponds, with salinities varying from that of the Bay to 215,000 ppm. A composite salinity averaging 21,000 ppm was chosen to represent intruding water, since this appears to be the average salinity of ground water in the upper aquifer around the perimeter of the Bay.

The volume of salt water present in each of the aquifers in the spring of the years 1963 and 1972 are based on the isochlors, the salinity of intruding water (21,000 ppm), and the storage capacities of the aquifers. The annual amounts of saline water intruding the ground water basin were estimated by prorating the total amount of saline water between 1963 and 1972 on the basis of water levels in the forebay area bayward from the Hayward Fault. The annual amounts are listed in Table 3.

Although the total amount of salt in the basin has increased between 1963 and 1972, the annual rate of salt water entering the basin decreased from 1963 to 1972 due to the Alameda County Water District's ground water recharge program. The reduction in annual salt water intrusion rates would have been greater except for pumpage and wastage of water from the basin by the gravel quarries for more economic gravel extractions, and the interruptions in the recharge operations caused by the construction of the Alameda Creek Flood Control Channel. The wastage of pumpage to the Bay has been stopped and the construction of the flood control channel has been completed.

TABLE 3

ANNUAL AMOUNTS OF SALINE* INTRUSION
(In Acre-Feet)

Year	Amount	Year	Amount
1961-62	8,600	1966-67	3,100
1962-63	6,600	1967-68	1,100
1963-64	6,800	1968-69	1,100
1964-65	5,400	1969-70	1,700
1965-66	5,000	1970-71	1,700

*Saline water at 21,000 ppm equivalent salinity.

Effect of Saline Intrusion on Water Supply

During the study period the total amount of water supply available to the area has exceeded the total water use. The net result of this relationship and saline intrusion is shown by the well hydrographs in Figure 7. Annual amount of water use is the sum of ground water pumped and direct delivery of imported water to customers, and is shown in Table 4.

The hydrologic inventory in Chapter V shows that during the period 1961 to 1969, the total amount of water in storage increased by 76,000 acre-feet. Of this increase, 38,000 is attributable to saline intrusion and 38,000 to fresh water. During the two-year period 1969-71 there has been a decrease of water in storage of 11,000 acre-feet. This was the result of extractions exceeding fresh water recharge by 14,000 acre feet and a saline intrusion of 3,000 acre-feet.

Although the water levels have recovered and water supply available has exceeded water use, a part of the water level recovery was due to saline intrusion and results in a continuing presence of salt water within the basin. The ground water basin is still endangered, not only from the large amount of salt water now present in the basin, but also from the probability of additional intrusion during future dry periods.

TABLE 4

ANNUAL AMOUNTS OF WATER USE
(In Acre-Feet)

Year	Amount	Year	Amount
1961-62	43,800	1966-67	44,400
1962-63	39,300	1967-68	48,500
1963-64	45,400	1968-69	54,400
1964-65	46,600	1969-70	53,700
1965-66	49,200	1970-71	48,900

Control of Saline Intrusion

Various methods of protecting the ground water basin against further intrusion and for removal of the existing salts have been reviewed. A pumping barrier is recommended as the basic plan deserving further study and the plan which can be used to judge other alternatives. This type of plan is recommended because it will not cause saline water inland of the proposed barrier location to be forced farther inland into fresh water areas such as a recharge mound type of barrier would do, and the pumping barrier will assist in the removal of salt water from the upper aquifer.

Previous work by the Department in both the Oxnard and Fremont areas assures that a pumping barrier is physically feasible.

The magnitude of the cost of installing a pumping barrier was arrived at by developing the conceptual plan shown on Figure 8. The barrier plan is anchored on the Coyote Hills and uses 14 pumping wells to form a protective arc around the major production portions of the Newark aquifer. The capital cost of the system including wells, pumps, monitoring points and equipment, lands, discharge facilities and power service is estimated to be $1.2 million. The annual operations, maintenance and replacement costs are estimated to be $100,000.

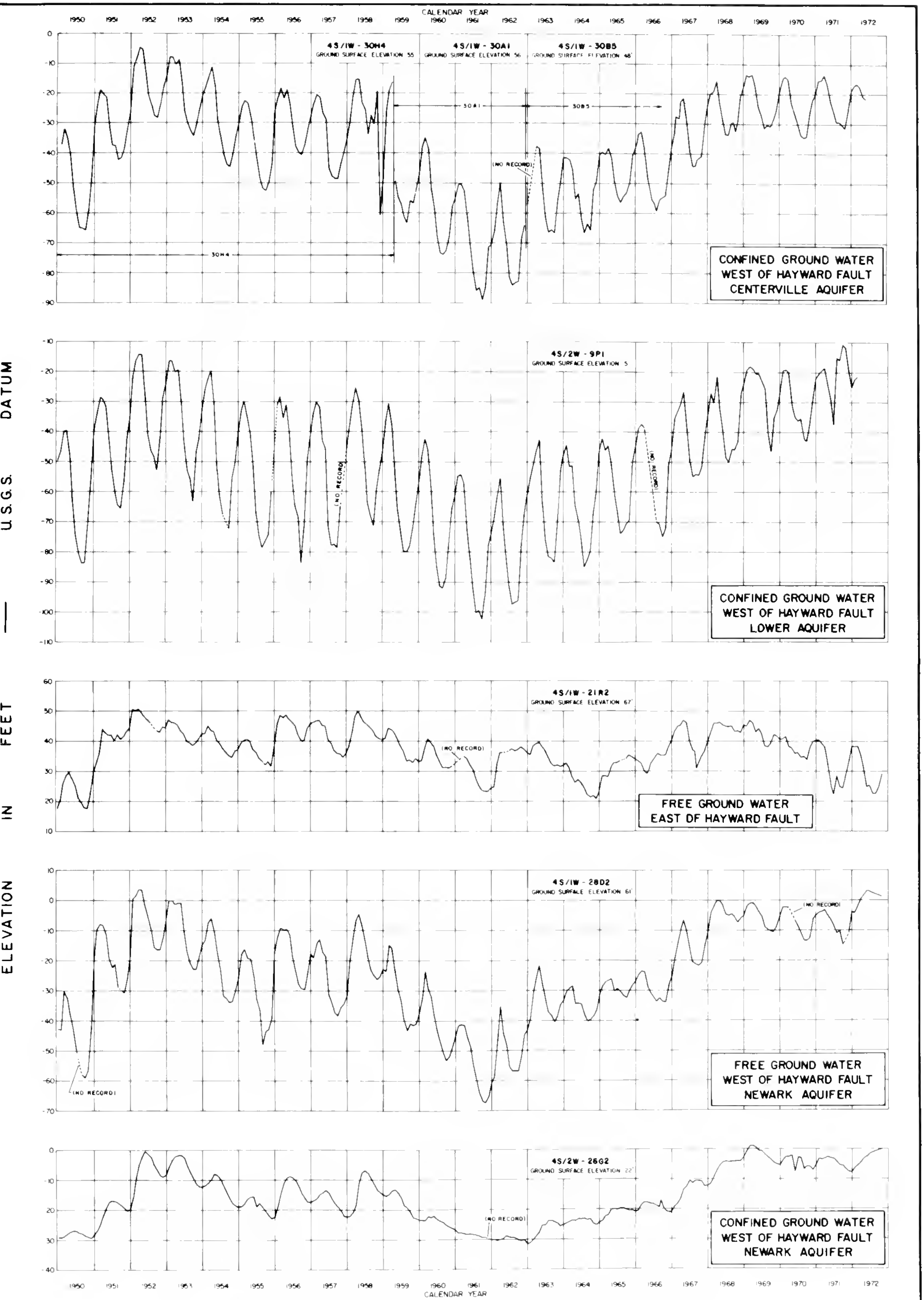


Figure 7. HYDROGRAPHS AT SELECTED WELLS

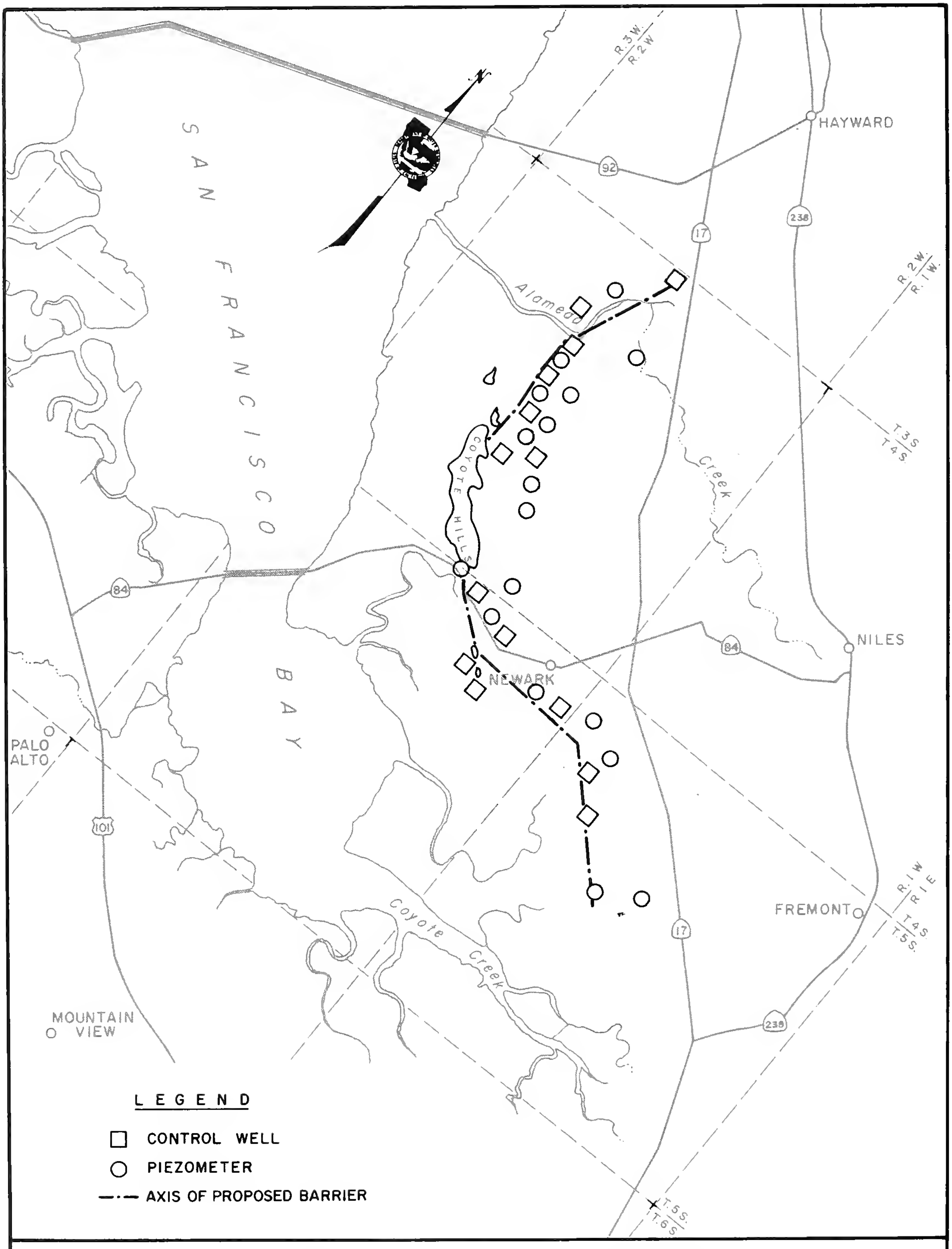


Figure 8. CONCEPTUAL PLAN FOR PROPOSED BARRIER

CHAPTER V. EVALUATION OF HISTORIC WATER SUPPLY AND DISPOSAL

The development of an inventory of supply to and disposal from the ground water basin provides a gross view of how the ground water basin is affected by climate and man's works. When the inventory is performed on many small pieces of the basin, as in modeling, the operational characteristics of the basin become clear. In both the gross inventory of the basin and in the modeling approach, supply and disposal are combined to obtain a theoretical change in storage. These changes are compared to the historic changes to verify the accuracy of the inventory and model. The model may then be used to test alternative plans for protection and operation of the ground water basin.

Study Area

The Fremont study area is the subsurface area influenced by Alameda Creek and adjacent smaller streams, and represents a manageable unit of the South Bay Ground Water Basin. For the purposes of this report the study area shown on Figure 1 has been approximated by the ground water model shown in Figure 9.

Ground Water Model

The model configuration shown in Figure 9 is a modification of that described in Appendix E of the 1968 report. The area covered by the model has been enlarged to better approximate the study area. The arrangement of individual nodal areas (polygons) has been modified to conform to the more detailed geologic and hydrologic interpretations. The southern end of the study area is an area of overlap of depositions of Alameda Creek and Santa Clara streams. This overlap condition has been simulated by using nodes 22 through 26 of the Fremont model in the model of the Santa Clara ground water area.

For the purposes of this report, the amounts of recharge, pumpage and change in storage are shown for the total ground water basin. This information will be determined for each nodal area in the model, then verified and used for planning of the salinity barrier.

Study Period

In selection of a segment of time to use as a study period, it is desirable to specify certain criteria. The hydrologic condition during the study period should reasonably represent a long-time hydrologic condition. The time segment selected should begin at the end of a dry period and should end at the conclusion of a dry period in order to minimize the difference between the amount of water in transit in the zone of aeration between the beginning and end of the study period. The time segment should be within the period of available records, and if recent

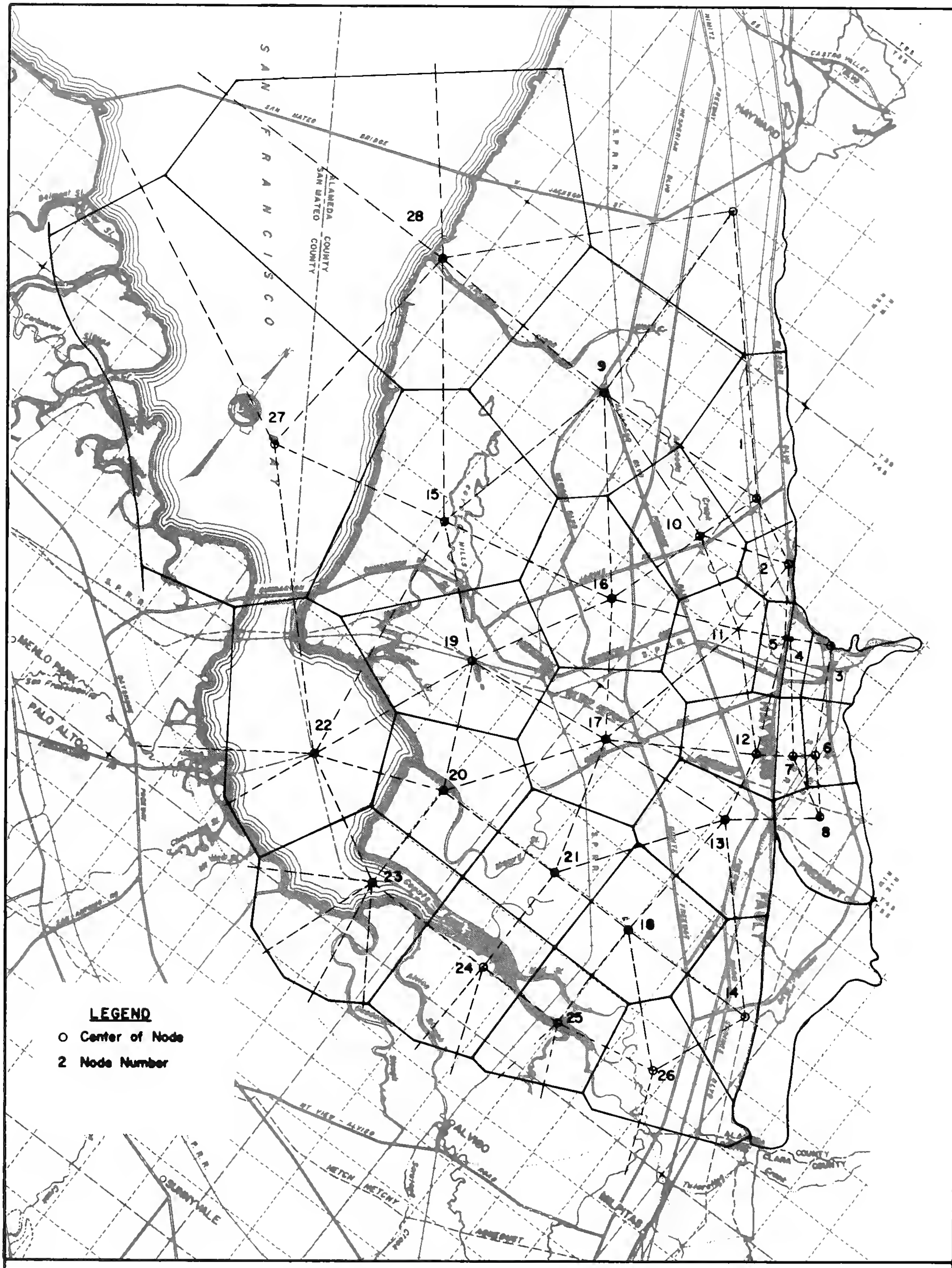


Figure 9. MATHEMATICAL MODEL

cultural conditions have been recorded, this information can aid in determination of the effect of urbanization on recharge to the ground water.

The August 1967 report used a 16-year study period, water years 1949-50 through 1964-65. This report uses a 9-year period, water years 1961-62 through 1969-70. The year 1961-62 was selected as the initial year because that year was the beginning of recharge of water from the State's South Bay Aqueduct and it was preceded by a year of below normal precipitation. The relative amounts of annual precipitation during the long term record, the base period, and the study period are shown on Figure 10. The long time average period of 94 years was not changed because the longer period of record now available did not change the average precipitation.

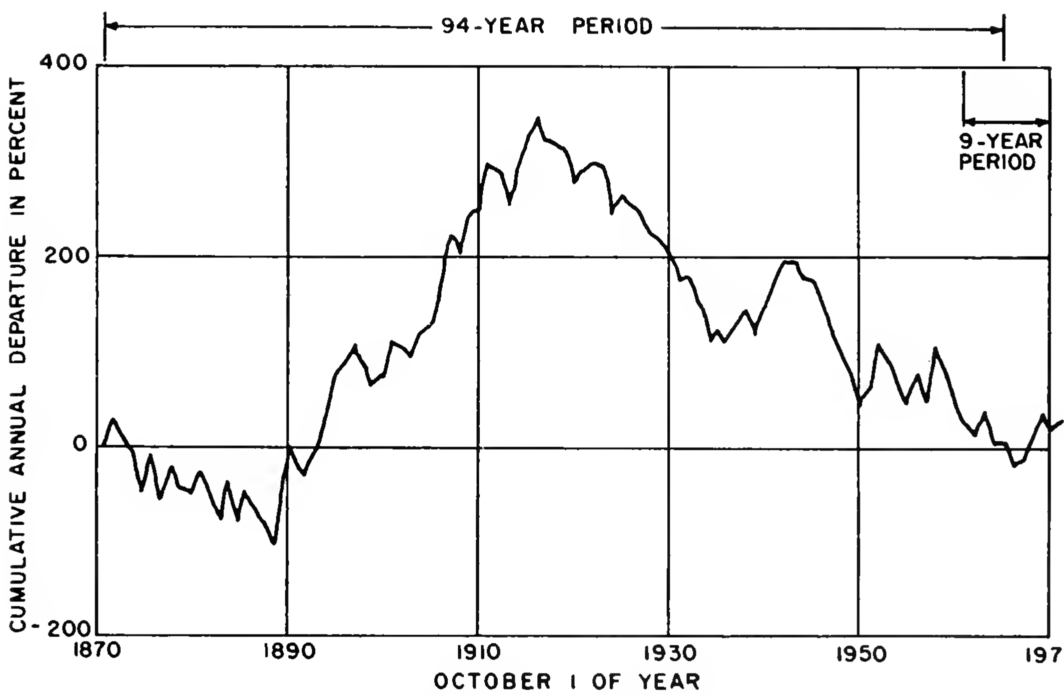


FIGURE 10 - CUMULATIVE DEPARTURE OF ANNUAL PRECIPITATION FROM 94 YEAR MEAN

General Conditions

The general factors affecting the ground water basin are precipitation, streamflow, land use and imported water.

Precipitation

Precipitation for the entire period of record for gages in the vicinity of Niles is shown in Table 5. The 94-year average used in the 1968 report has been retained as long term average, since the additional record had no effect on the average. The 9-year period 1961-62 through 1969-70 has about the same average annual precipitation as the 94-year average.

Streamflow

Alameda Creek is the main stream traversing the forebay of the area. Flow measurements since 1891-92 are available for the creek where it enters the area near Niles and for three years, 1916-1919, for the lower end of the recharge area near Decoto. Main flows now leave the area by a new channel, Patterson Creek, but the old Alameda Creek continued to receive excess flows until 1967. Both of the outflow channels have been gaged since 1958-59. The Alameda Creek Flood Control Channel, which improved Patterson Creek, was completed beyond this point in 1967; thereafter all of the flows passed down that channel. Dry Creek, located near the upper end of the area and tributary to the Alameda Creek lower gage, is also measured.

Flows of other streams tributary to the study area were estimated by correlation with gaged streams. Recorded amounts of runoff are shown in Table 6. Estimated amounts of annual runoff from ungaged tributary areas are shown in Table 7.

Land Use

The study area continues to be in transition from an agricultural to urban economy. The change in land use within the model area of 108,040 acres during the study period is shown in Table 8. Land use within the boundaries of the Alameda County Water District is shown on the plate following page 57.

Imported Water

Agencies in the study area purchase water from two suppliers of imported water: the City of San Francisco and the State of California.

Annual Deliveries

Amounts of water imported from the City of San Francisco's aqueducts and from the State of California's South Bay Aqueduct are listed in Table 9.

TABLE 5

ANNUAL PRECIPITATION AND INDEX OF WETNESS
1871-1970

Water Year	Inches a/	Index of Wetness b/	Water Year	Inches	Index of Wetness	Water Year	Inches	Index of Wetness
1871-72	22.65	125	1905-06	24.20	133	1940-41	25.35	140
72-73	14.31	79	06-07	28.85	159	41-42	21.23	117
73-74	14.17	78	07-08	15.12	83	42-43	18.29	101
74-75	11.74	65	08-09	25.10	138	43-44	15.38	85
			09-10	18.65	103	44-45	16.82	93
1875-76	25.88	142	1910-11	27.59	152	1945-46	14.39	79
76-77	9.34	51	11-12	15.80	87	46-47	12.60	69
77-78	24.67	136	12-13	12.06	66	47-48	14.72	81
78-79	14.54	80	13-14	22.95	127	48-49	12.72	70
79-80	17.70	97	14-15	27.34	150	49-50	14.00	77
1880-81	20.14	111	1915-16	21.38	118	1950-51	20.21	111
81-82	13.91	77	16-17	13.50	74	51-52	26.26	145
82-83	14.07	78	17-18	18.15	100	52-53	15.50	85
83-84	25.88	142	18-19	17.49	96	53-54	13.50	74
84-85	10.36	57	19-20	11.06	61	54-55	14.90	82
1885-86	23.35	128	1920-21	20.62	113	1955-56	23.85	131
86-87	15.37	85	21-22	19.85	109	56-57	12.99	71
87-88	14.67	81	22-23	17.89	98	57-58	28.30	156
88-89	15.67	86	23-24	8.63	47	58-59	12.30	68
89-90	36.36	200	24-25	21.65	119	59-60	13.83	76
1890-91	14.04	77	1925-26	16.35	90	1960-61	14.03	77
91-92	16.18	89	26-27	18.79	103	61-62	15.86	87
92-93	23.72	131	27-28	16.55	91	62-63	22.58	124
93-94	23.19	128	28-29	14.48	80	63-64	11.99	66
94-95	26.63	147	29-30	14.78	81	64-65	18.14	100
1895-96	20.33	112	1930-31	12.22	67	1965-66	14.02	77
96-97	22.72	125	31-32	18.87	104	66-67	25.41	140
97-98	13.58	75	32-33	13.70	75	67-68	15.06	83
98-99	14.52	80	33-34	10.66	59	68-69	23.67	130
99-00	19.30	106	34-35	19.77	109	69-70	15.30	84
1900-01	25.22	139	1935-36	16.69	92	1970-71	19.96	110
01-02	17.12	94	36-37	19.78	109			
02-03	17.20	95	37-38	21.80	120			
03-04	21.91	121	38-39	13.33	73			
04-05	20.19	111	39-40	22.20	122			
Averages			94 years 1871-1965	18.17	100	9 years 1961-70	18.00	99

a/ 1871-72 thru 1884-85 Weather Bureau's Niles Precipitation Station (SP Depot)
1885-86 thru 1932-33 Niles 1 SW Precipitation Station
1933-34 thru 1957-58 Niles 1 S Precipitation Station
1958-59 thru 1969-70 Alameda County Corp. Yard Precipitation Station

b/ Index of Wetness is the percent of 94-year average.

TABLE 6

RECORDED ANNUAL RUNOFF
(In Acre-Feet)

Alameda Creek Near Niles

Year	Amount	Year	Amount	Year	Amount
		1920-21	72,400	1950-51	115,200
1891-92	56,000	21-22	131,000	51-52	291,100
92-93	360,000	22-23	58,000	52-53	24,700
93-94	147,000	23-24	2,060	53-54	4,250
94-95	263,000	24-25	18,700	54-55	5,900
1895-96	118,000	1925-26	31,000	1955-56	214,100
96-97	204,000	26-27	48,300	56-57	7,880
97-98	7,020	27-28	30,100	57-58	245,700
98-99	64,100	28-29	5,240	58-59	14,660
99-00	51,700	29-30	19,200	59-60	11,940
1900-01	119,000	1930-31	1,220	1960-61	650
01-02	83,800	31-32	57,400	61-62	34,740
02-03	110,000	32-33	6,980	62-63	66,660
03-04	98,300	33-34	7,920	63-64	22,940
04-05	45,400	34-35	30,490	64-65	85,620
1905-06	203,000	1935-36	77,150	1965-66	26,320
06-07	324,000	36-37	100,100	66-67	140,000
07-08	46,500	37-38	286,000	67-68	41,510
08-09	239,000	38-39	15,220	68-69	110,100
09-10	84,200	39-40	92,580	69-70	58,120
1910-11	272,000	1940-41	200,000	1970-71	42,300
11-12	16,500	41-42	128,100		
12-13	6,550	42-43	79,490		
13-14	179,000	43-44	35,010		
14-15	182,000	44-45	48,430		
1915-16	233,000	1945-46	15,740		
16-17	86,000	46-47	2,080		
17-18	12,600	47-48	899		
18-19	107,000	48-49	5,610		
19-20	8,250	49-50	8,680		

Table 6 (continued)

Patterson Creek Near Union City

Year	Amount	Year	Amount	Year	Amount
1958-59	10,410	1963-64	4,240	1967-68	6,020
59-60	7,290	64-65	60,960	68-69	98,820
60-61	7,290	65-66	7,160	69-70	40,620
61-62	22,640	66-67	118,200	70-71	31,680
62-63	42,800				

Alameda Creek Near Decoto

Year	Amount	Year	Amount	Year	Amount
1916-17	74,000	1917-18	7,200	1918-19	91,400

Alameda Creek at Union City

Year	Amount	Year	Amount	Year	Amount
1958-59	140	1963-64	99	1967-68	32
59-60	614	64-65	5,590	68-69	0.6
60-61	0	65-66	560	69-70	160
61-62	1,300	66-67	266	70-71	723
62-63	3,860				

Dry Creek at Union City

Year	Amount	Year	Amount	Year	Amount
1916-17	957	1961-62	1,060	1966-67	2,930
17-18	61	62-63	1,970	67-68	612
18-19	1,330	63-64	224	68-69	3,580
1959-60	463	64-65	1,820	69-70	1,680
60-61	8	65-66	323	70-71	1,580

TABLE 7

UNGAGED TRIBUTARY HILLSIDE RUNOFF
(In Acre-Feet)

Year	Tributary to Node 1[a]	2	4	3[b]	6	8	13	14
1961-62	300	80	15	140	45	375	240	480
62-63	2,610	245	40	445	140	1,170	755	1,510
63-64	310	30	5	50	15	135	90	175
64-65	565	125	20	232	70	610	395	785
1965-66	600	50	10	90	25	235	155	305
66-67	3,880	365	60	662	200	1,745	1,130	2,245
67-68	650	70	10	123	35	320	210	420
68-69	1,780	285	45	520	155	1,370	885	1,765
69-70	80	70	10	130	40	335	215	435
1970-71	80	175	30	315	95	835	540	1,075

a - Does not include gaged flow of Dry Creek at Union City (Table 6).
b - Does not include gaged flow of Alameda Creek near Niles (Table 6).

TABLE 8

LAND USE, FREMONT MODEL AREA
(In Acres)

Model Area - 108,040 Acres

Year	Irrigated Agriculture	Municipal and Industrial	Salt Ponds	Water Surface*	Dry Farm and Native
1961-62	12,850	8,420	24,200	25,430	37,140
62-63	11,990	10,010	24,200	25,430	36,410
63-64	11,520	10,710	24,200	25,430	36,180
64-65	11,100	11,200	24,200	25,430	36,110
1965-66	10,670	11,700	24,200	25,430	36,040
66-67	10,240	12,200	24,200	25,430	35,970
67-68	9,810	12,690	24,200	25,430	35,910
68-69	9,390	13,190	24,200	25,430	35,830
69-70	6,700	14,610	24,200	25,430	37,100

*Includes San Francisco Bay

TABLE 9

IMPORTED WATER
(In 1,000 Acre-Feet)

Water Year	Source: City of San Francisco: Bunting Pit (1)	Source: City of San Francisco: Alameda Creek (2)	Source: City of San Francisco: Hetch Hetchy (3)	Source: State of California (4)	Total For Recharge (5)=(1)+(2)+(4)	Total For All Uses (6)=(3)+(5)
1961-62	- 2.33* -		1.17	5.47	7.80	8.97
62-63	1.12	1.05	0.82	11.20	13.37	14.19
63-64	1.34	0.46	1.74	18.23	20.03	21.77
64-65	5.31	0.41	1.80	16.25	21.97	23.77
1965-66	2.57	0.53	3.10	15.04	18.14	21.24
66-67	5.55	1.60	5.70	8.21	15.36	21.06
67-68	4.04	0.38	3.46	28.60	33.02	36.48
68-69	5.56	1.17	3.86	13.41	20.14	24.00
69-70	3.64	1.03	3.59	14.56	19.23	22.82
1970-71	3.18	2.17	5.57	10.13	15.48	21.05

*Sum of amounts for Bunting Pit and Alameda Creek.

City of San Francisco

Through its Hetch Hetchy Aqueduct, the City of San Francisco delivers treated water to the cities of Hayward and Milpitas and to the Alameda County Water District. All of this supply is served to customers of the local water systems, and is accounted for in the inventory as recharge of applied water. Alameda County Water District also receives small amounts of water from the City of San Francisco's Sunol Aqueduct. This water is delivered to the Bunting Pits (located on the south side of Alameda Creek west of Mission Boulevard) for recharge and to other users along Alameda Creek.

State of California

The South Bay Aqueduct of the California State Water Project has been a source of recharge water to the Fremont area since 1962, when the first section to be completed was put into operation. Water was released from the aqueduct at the Altamont Turnout and flowed through the Livermore Valley to Niles until 1965, when the remainder of the aqueduct was completed. Since then water has been released to Alameda Creek at the Vallecitos Turnout.

The ground water is recharged by water from the South Bay Aqueduct, released to flow in Alameda Creek, and then diverted into adjacent gravel pits near Niles.

Ground Water Inventory

A schematic representation of the hydrologic system is shown on Figure 11. The reference, or free body, used in the ground water inventory is the ground water in storage. The inventory is made on an annual basis, and under the assumption that water which percolates below the root zone will reach the ground water mass during the same water year. The inventory can be represented by the simple equation: Supply - Withdrawal = Change in Storage.

Items of supply, or recharge, to the ground water are derived mainly from precipitation, storm runoff, imported water, and pumped ground water. Specifically, the items of supply are:

1. Portion of precipitation percolating to ground water.

2. Portion of storm runoff, or streamflow, including imported water released into Alameda Creek and adjacent gravel pits, percolating to ground water.

3. Portion of applied (delivered) water percolating to ground water. (Applied water included pumped ground water and imported water put directly into water distribution systems.)

4. Subsurface inflow.

5. Water released by compaction of clay beds.

Withdrawals from the ground water consist of ground water pumpage and subsurface flow out of the basin.

Change in storage is the annual volume of ground water gained or lost from storage.

Direct Recharge of Precipitation and Delivered Water

The disposition of combined amounts of precipitation and applied water to evapo-transpiration, recharge, and runoff are computed for each type of land use. Starting at the beginning of a water year, and on a monthly-accounting basis, from October through April, the monthly amounts of precipitation and applied water are used to satisfy the soil moisture deficiency and potential evapo-transpiration consumptive use. The same process is followed during the summer growing season, but on a lump sum basis. During the growing season the amount of recharge must also be at least 20 percent of the applied water to allow for irrigation when roots had not developed their maximum ability to take moisture. Monthly potential evapo-transpiration rates, moisture holding content of soils, and effective rooting depths for crops are shown on Table 10.

Since records on the amounts of water applied to individual crops are available only for 1972, data concerning annual amounts of applied water for the Northern Santa Clara County study area to the south were used for the Fremont area. As in the Santa Clara study, total irrigation during years before a pump tax was imposed was assumed to be one irrigation greater than in years after the pump tax.

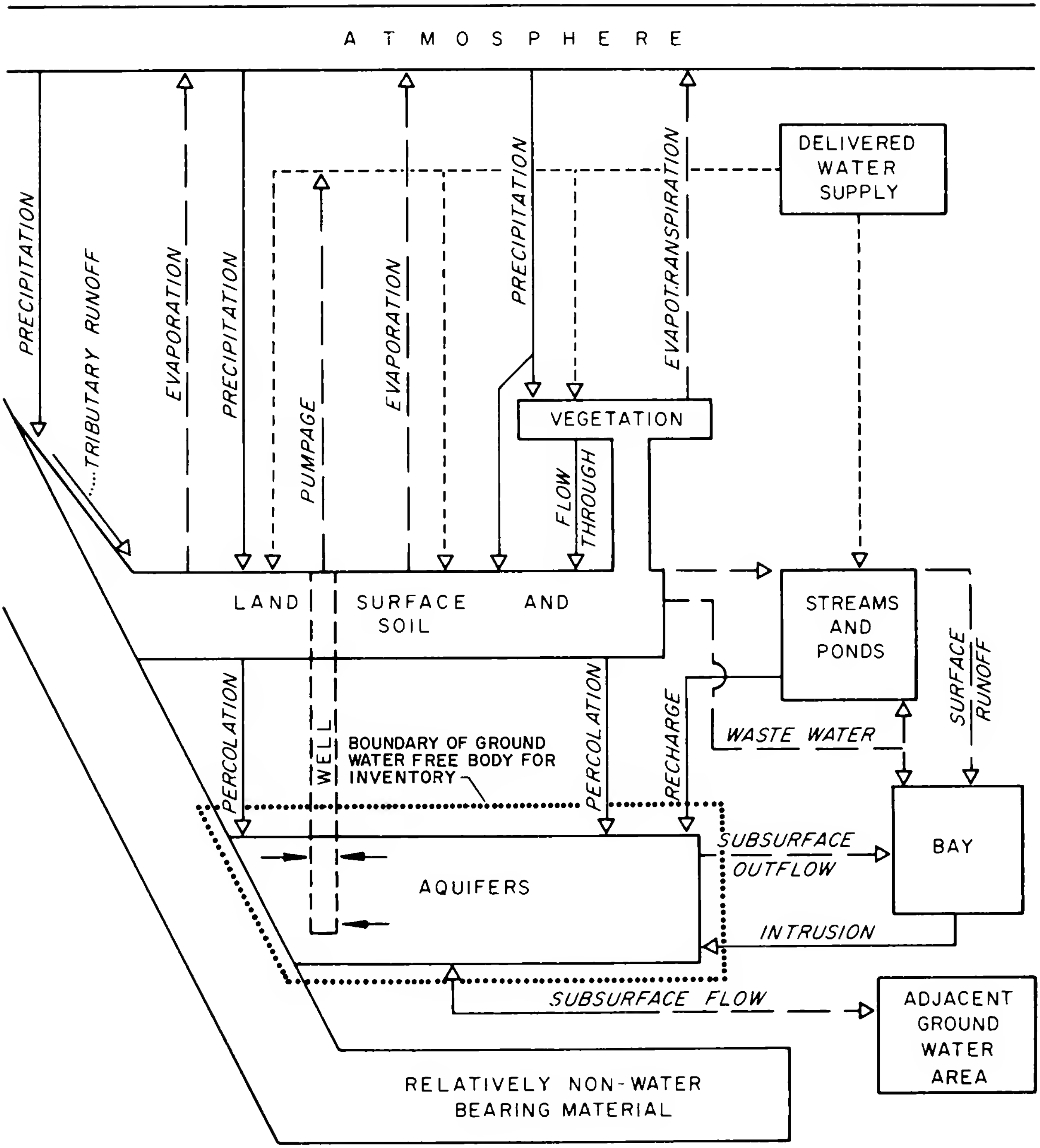


Figure II. HYDROLOGIC SYSTEM (SCHEMATIC)

TABLE 10

AGRICULTURAL WATER USE FACTORS

Monthly Potential Evapo-Transpiration
(In Inches)

Month	Improved Pasture*	Alfalfa	Sugar Beets	Deciduous Orchard	Nonirrigated Barley
October	3.5	3.5	3.5	2.7	2.0
November	1.7	1.7	1.7	1.1	1.7
December	0.9	0.9	0.9	0.9	0.9
January	1.1	1.1	1.0	1.1	1.1
February	1.0	1.0	1.3	1.4	1.9
March	3.1	2.9	-	2.1	3.1
April	4.6	4.1	-	3.2	3.4
May	5.7	5.1	1.7	4.6	1.2
June	7.3	6.5	5.6	6.2	0.4
July	7.4	6.8	7.7	6.8	0.0
August	6.5	6.2	6.6	5.8	0.0
September	4.9	4.8	5.3	4.3	0.3

*Evapo-transpiration of improved pasture considered equivalent to potential evapo-transpiration.

Moisture Holding Content for Soils
(In Inches per Foot of Soil)

Soil Type	Available Water Content	Soil Type	Available Water Content
Sand	1.0	Silty Clay	1.7
Clay	1.0 to 1.5	Silty Clay Loam	2.0
Clay Loam	1.4	Silt Loam	2.3
Loam	1.7	Silt	2.9

Effective Rooting Depth
(In Feet)

Irrigated Crop	Effective Root Depth	Irrigated Crop	Effective Root Depth
Pasture	2	Misc. Truck	3
Alfalfa	6	Tomatoes	5
Sugar Beets	5	Orchard, Mixed	6
General Field	4	Vineyard	5
Walnuts	8		

Annual amounts of applied irrigation water varied according to the amount of rainfall occurring in February, March, and April, since rainfall in these months controls the moisture in the soil at the start of the growing season. Annual amounts of water applied to irrigated lands are listed in Table 11. Applied water on urban areas was assumed to be a depth of three feet on the pervious area.

Annual amounts of rainfall becoming local runoff are computed as rainfall on impervious areas less evaporation. Average daily rates of rainfall evaporation are listed in Table 12. For irrigated and native lands, 10 percent is assumed to be impervious. For urban areas, 50 percent is assumed impervious. The depth of runoff is shown on Table 13.

Depth of Recharge

The maximum depth of recharge shown on Table 13 for each nodal area and year was computed for irrigated agricultural, native, and urban lands east of the salt evaporation ponds. For irrigated agriculture the value was computed for each nodal area based on the crop pattern of 1967.

Annual Recharge

The annual amounts of direct recharge (from rain and delivered water) are the products of the land use areas and the depth of recharge amount for the specific land use. The amount of recharge actually occurring will be less than this computed amount due to the high percentages of clay present in some portions of the area. To correct for the low permeability of the clay areas, the distance from the apex of the Alameda Creek cone were taken into account. The effect of distance from the apex of the cone is shown in Figure 12. The clay content for each node is shown on Figure 13. Annual amounts of recharge corrected by the recharge factors are listed in Table 14 on page 56.

Recharge from Streamflow

Streamflow available for recharge is the sum of flows originating in the hills to the west and local runoff from the surface of the study area. Local runoff originating on the valley lands of the study area is that portion of precipitation not consumed or percolating to ground water. On its way to San Francisco Bay or a gaged channel, a portion of this local runoff may percolate. Due to the location of recharge facilities and gaging stations, the analysis of runoff has been divided into analysis of the gaged portion of the study area bounded by Alameda Creek, Dry Creek, and the hills to the northeast, and analysis of runoff in the remaining ungaged study area, less the Bay and the salt ponds.

Alameda and Dry Creeks Area

In the area bounded by Alameda Creek, Dry Creek, and the hills to the northeast, surface flows available for percolation include those passing the upper gage on Alameda Creek and the Dry Creek gage, tributary ungaged runoff from the hills to the north, and local runoff developed within this area.

TABLE 11

DEPTHS OF APPLIED WATER
(In Feet)*

Water Year	Deciduous	Pasture	Tomato	Cole	Average
1961-62	1.20	2.40	1.95	2.40	1.89
62-63	1.05	1.95	1.50	1.95	1.60
63-64	1.80	2.56	2.03	2.56	2.15
64-65	1.20	2.03	1.65	2.03	1.72
1965-66	1.80	2.56	2.03	2.56	2.15
66-67	1.05	1.95	1.50	1.95	1.60
67-68	1.50	2.40	1.95	2.40	1.12
68-69	1.20	2.03	1.65	2.03	1.72
69-70	1.35	2.25	1.80	2.25	1.94

*Acre-feet per gross acre with 10 percent of gross area assumed as impervious.

TABLE 12

AVERAGE DAILY EVAPORATION RATES
(In Inches)

Month	During Storm	After Storm
October	0.040	0.063
November	0.024	0.038
December	0.014	0.019
January	0.023	0.024
February	0.037	0.077
March	0.055	0.121
April	0.074	0.170
May	0.081	0.191
June	0.063	0.218
July	0.037	0.183
August	0.073	0.171
September	---	0.119

TABLE 13

DEPTHS OF RECHARGE AND RUNOFF
FROM APPLIED WATER AND PRECIPITATION
(In Feet)

Water Year	Recharge From: Irrigated Land	Recharge From: Urban Land	Recharge From: Dry Farm Land	Runoff From: Urban Land	Runoff From: Nonurban Land
1961-62	0.64	0.56	0.31	0.40	0.10
62-63	0.64	0.44	0.31	0.56	0.14
63-64	0.58	0.38	0.13	0.25	0.06
64-65	0.61	0.42	0.30	0.44	0.11
1965-66	0.65	0.40	0.24	0.34	0.08
66-67	0.81	0.56	0.67	0.65	0.16
67-68	0.77	0.22	0.09	0.34	0.08
68-69	0.89	0.62	0.74	0.61	0.15
69-70	0.59	0.26	0.28	0.38	0.09

A portion of the flow in Alameda Creek is diverted into percolation pits by the Alameda County Water District. The only known surface diversions during the study period are those made by the District. During the last part of the study period, pumpage by gravel pit operators to control water levels in the pits was discharged to Alameda Creek.

Recharge in the Alameda Creek-Dry Creek area is the total runoff available less outflow. The total runoff is the sum of flows in Dry Creek and Alameda Creek at the upstream boundary of the study area, plus local runoff and stream discharges produced within the area. The method of determining the amount of local runoff is described in the section on determining runoff in the remainder of the study area. Recharge from runoff in Alameda Creek, as shown on Table 14, contains releases from the South Bay Aqueduct of the State Water Project, and is computed on the basis of flows measured at Niles gage and Dry Creek gage. The amounts of recharge from runoff shown in Table 14 include recharge in the total area, including the pits. The amounts of South Bay Aqueduct water purchased by the Alameda County Water District are shown in Table 9.

Remainder of Study Area

The ungaged tributary hillside runoff and the runoff from precipitation are available for percolation on their way to the Bay. Local runoff is computed from land use in Table 5 and depth of runoff in Table 13. The ability of streamflow to become recharge to the ground water is regulated by the pervious areas of the channels conveying the water, the length of time flow

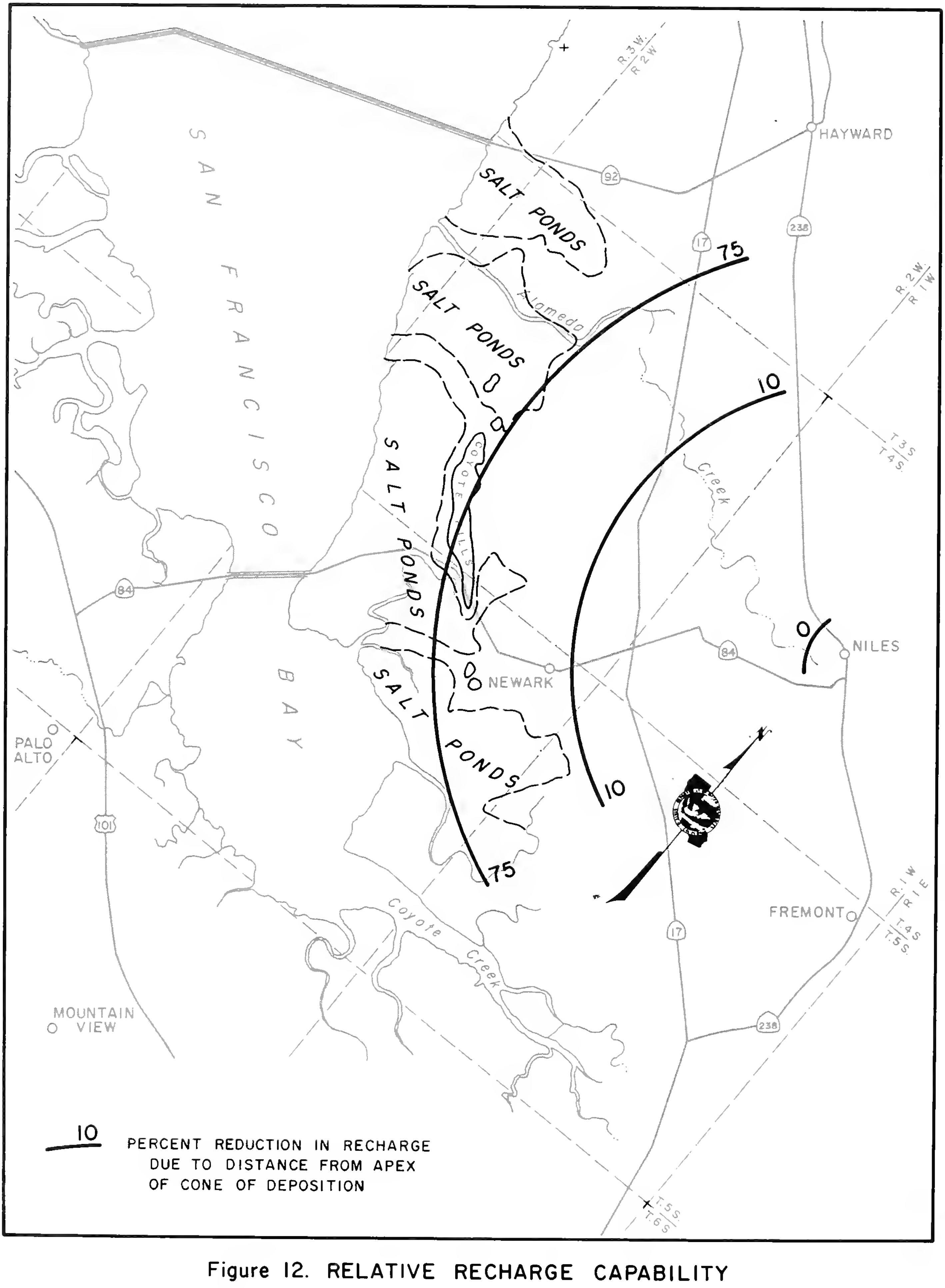


Figure 12. RELATIVE RECHARGE CAPABILITY

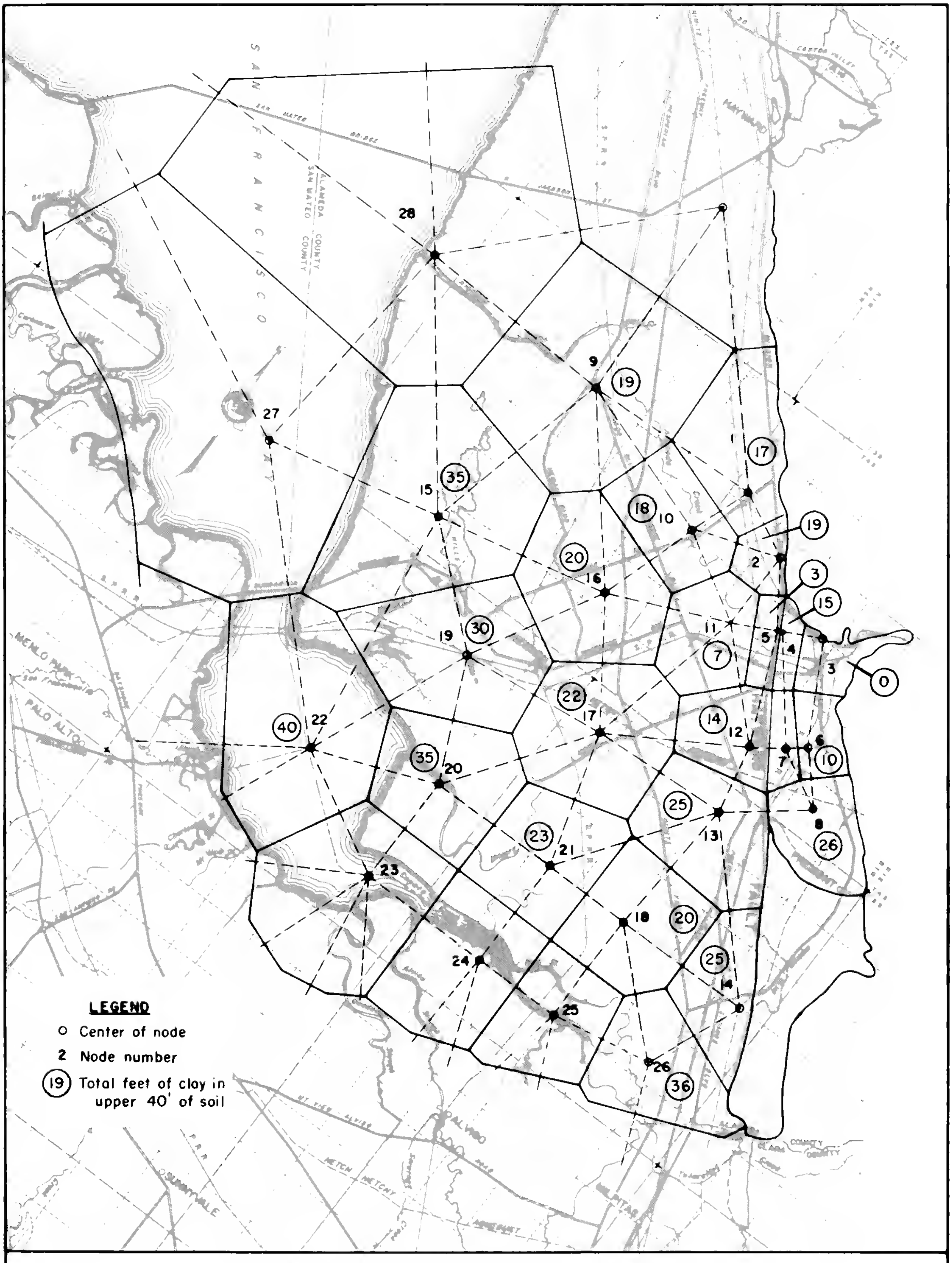


Figure 13. CLAY IN UPPER SOIL STRATA

takes place, and the surface and subsurface characteristics of the soil. In the more pervious portion of the area outside of the Alameda-Dry Creek area, percolation of runoff was determined for the sum of the following computations.

40 percent of the flows of 0 to 5,000 acre-feet
30 percent of the flows of 5,001 to 10,000 acre-feet
20 percent of the flows of 10,001 to 15,000 acre-feet

Subsurface Inflow

The combination of geologic interpretation of subsurface conditions in Node 8 (Figure 9) and the depth of wells in Node 8 indicate that the majority of pumpage in the node is from the Santa Clara Formation underlying the alluvium. To account for this condition, 90 percent of pumpage in Node 8 was estimated to be subsurface inflow.

Compaction of Clays

Subsidence occurred in the South Bay Area during years prior to 1969. The center of subsidence is south of San Francisco Bay in Santa Clara County. Subsidence is associated with high amounts of pumpage in northern Santa Clara County and most of the water released by compaction of the aquitards is an inflow to aquifers in the Santa Clara County area. Shallow, thin aquifers belonging to the Fremont and Santa Clara areas overlap each other in the Alviso area and deeper aquifers of the two systems probably merge. This situation requires that a portion of the water produced by compaction of clays be assigned to the Fremont area. The annual amount of 500 acre-feet per year determined for the August 1968 report has been used for years, through 1966-67, and 200 acre-feet for 1967-68. Subsidence did not occur after 1968.

Ground Water Pumpage

Ground water pumpage is made up of pumpage by Alameda County Water District, Citizens Utility Company, individual industries, individual domestics, and individual agricultural users. All except agriculture are based on information collected by Alameda County Water District. Estimates of agricultural pumpage are based on land use in Table 5 and unit applied water in Table 11. Annual amounts of pumpage are listed in Table 4.

Saline Water Inflow

Annual volumes of saline water entering the ground water system are computed in Chapter IV.

Annual Inventory

An annual comparison of amounts of inflow to and outflow from the ground water system is shown in Table 14. Inflow is the sum of recharge from rain, applied water and runoff, subsurface flow, and saline intrusion. Outflow is the sum of municipal, industrial, and agricultural pumpage. The net recharge is comparable to the change in the amount of water in storage.

Change in Storage

The change in storage is computed as the product of annual change in water levels in the unconfined ground water area and the specific yield of materials in the zone of change. For this computation clays were given a specific yield value of one percent. Annual amounts of change in storage and the comparison with amounts of net recharge are shown in Table 15. Net recharge is computed as the difference between withdrawals and additions of water to the ground water system, and includes pumpage, recharge from rain, runoff and applied water, subsurface inflow, water from subsidence and sea water intrusion. Change in storage and net recharge are computed independently and should be approximately equal. The overall trends of both computations, as shown by their summation plots on Figure 14, are similar and their differences within reasonable limits.

TABLE 14

GROUND WATER INVENTORY

(In 1,000 Acre-Feet)

Year	Pumpage: Municipal, Industrial	Pumpage: Agricultural	Recharge From: Rain and Applied Water	Recharge From: Runoff: Alameda and Dry Creek	Recharge From: Runoff: Remainder of Area	Subsurface Flow	Compaction	Saline Intrusion	Net Recharge
1961-62	14.5	26.3	13.5	15.9	2.2	0.7	0.5	8.6	0.6
1962-63	16.6	19.8	12.6	29.4	3.5	1.4	0.5	6.6	17.6
1963-64	18.5	23.6	9.5	21.9	1.4	1.4	0.5	6.8	- 0.6
1964-65	21.5	19.6	11.7	29.1	2.8	0.8	0.5	5.4	9.2
1965-66	22.0	24.0	11.4	23.9	2.0	0.9	0.5	5.0	- 2.3
1966-67	19.6	17.1	18.9	38.9	4.3	0.5	0.5	3.1	29.5
1967-68	26.7	20.5	7.2	44.7	2.2	0.5	0.2	1.1	8.7
1968-69	34.3	16.5	20.5	35.8	4.0	0.5	0	1.7	11.7
1969-70	38.2	13.1	9.2	33.8	2.4	1.4	0	1.7	- 2.8

TABLE 15

CHANGE IN STORAGE

(In 1,000 Acre-Feet)

Year	Change in Storage (1)	Net Recharge (2)	Accumulated: Change in Storage (3)	Accumulated: Net Recharge (4)	Accumulated: Difference (5)=(3)-(4)
1961-62	- 4.3	0.6	- 4.3	0.6	- 4.9
1962-63	7.1	17.6	2.8	18.2	-15.5
1963-64	8.8	- 0.6	11.6	17.6	- 6.0
1964-65	6.6	9.2	18.2	26.8	- 8.6
1965-66	8.0	- 2.3	26.2	24.5	1.7
1966-67	20.9	29.5	47.1	54.0	- 6.9
1967-68	12.5	8.7	59.6	62.7	- 3.1
1968-69	16.7	11.7	76.3	74.4	1.9
1969-70	- 6.4	- 2.8	69.9	71.6	- 1.7
1970-71	- 5.1		64.8		

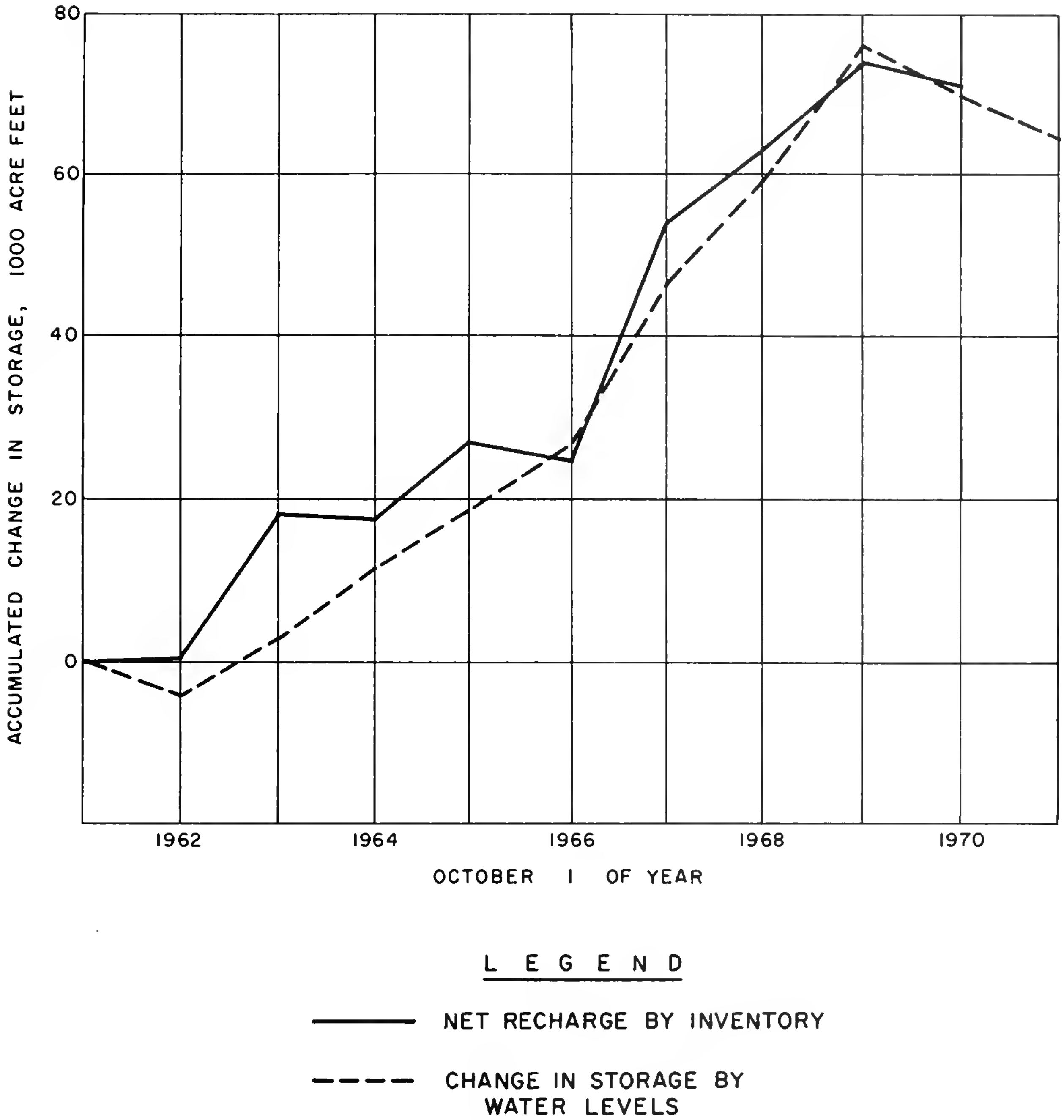


Figure 14. ACCUMULATED CHANGE IN STORAGE

LAND USE 1972
ALAMEDA COUNTY WATER DISTRICT
COLOR CODE
RESIDENTIAL & COMMERCIAL SERVED BY ACWD
RESIDENTIAL & COMMERCIAL SERVED BY CUC
IRRIGATED AGRICULTURE & RECREATION
INDUSTRIAL
DRY FARMING & IDLE LAND
SALT PONDS
MARSH LAND
SCALE OF MILES
1 0 1 2
1-9-73
N
DECOTO
NILES
MISSION SAN JOSE
MT EDEN
CENTERVILLE
IRVINGTON
WARM SPRINGS
NEWARK
COYOTE HILLS
SAN FRANCISCO BAY
ALAMEDA CO
SAN MATEO CO
SANTA CLARA CO

save water
DWR

Evaluation of Ground Water Resources South San Francisco Bay Vol. IV: South Santa Clara County Area

Department of Water Resources
in cooperation with Santa Clara Valley Water District

ON THE COVER. Off-stream ground water recharge facilities operated by the Santa Clara Valley Water District Some of these facilities have been in operation since before 1930.

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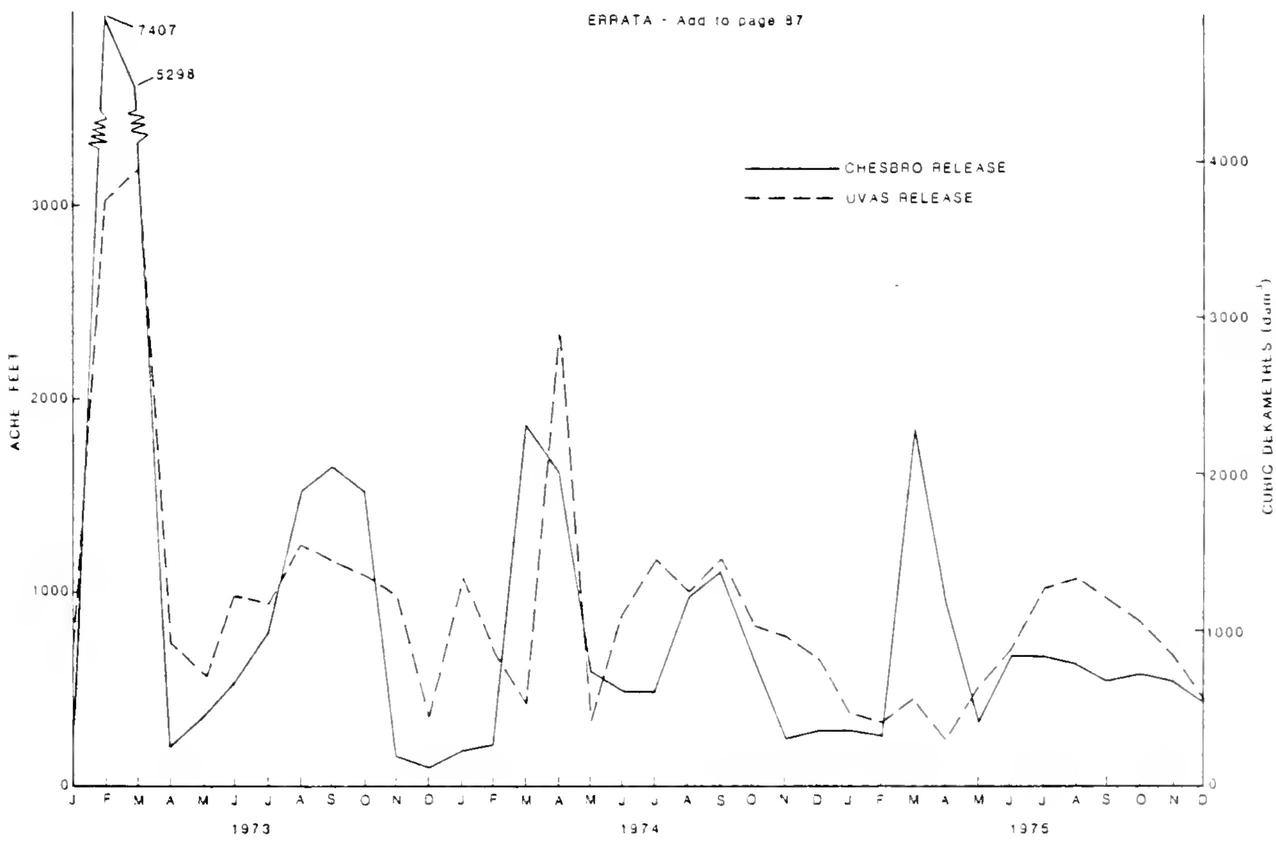

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Pg. 99. Correction replaces the two paragraphs on lower half of page.

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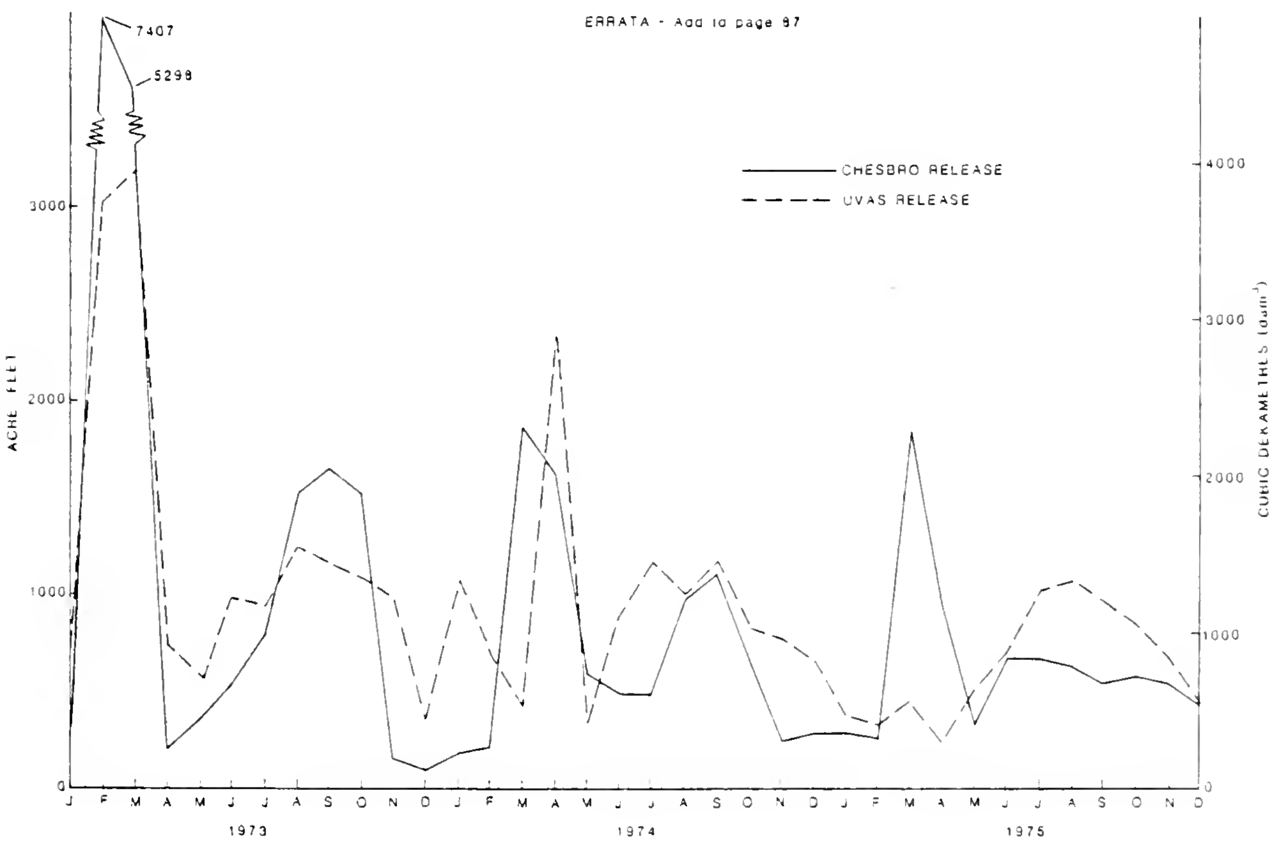

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Department of Water Resources
in cooperation with
Santa Clara Valley Water District

Bulletin 118-1

Evaluation of Ground Water Resources South San Francisco Bay Vol. IV: South Santa Clara County Area

May 1981

Huey D. Johnson
Secretary for Resources

Edmund G. Brown Jr.
Governor

Ronald B. Robie
Director

The Resources Agency

State of California

Department of Water Resources

FOREWORD

This bulletin provides an evaluation of the ground water resources of South Santa Clara Valley, located in the southern portion of Santa Clara County. It also touches on the resources of a portion of the adjacent Hollister ground water basin in northern San Benito County. The bulletin is the result of a cooperative investigation undertaken by the Department of Water Resources (DWR) and the Santa Clara Valley Water District (SCVWD).

The SCVWD service area is of special interest because it has one of the best-managed water resource programs in California. Ground water traditionally has been a major source of water supply in the area. As a result, SCVWD has developed a successful conjunctive water use program involving local surface water, artificial recharge, water conservation and waste water reclamation. The water district also receives imported water supplies from the State Water Project and the San Francisco Water Department (Hetch Hetchy) system; in the future it will receive water from the San Felipe Project, which is being constructed by the U. S. Water and Power Resources Service. Even with this well coordinated water program, population growth and increased industrial water use will reduce ground water in storage by the late 1980s, unless some corrective measures are taken.

Because SCVWD pursues such a highly developed conjunctive water use philosophy, other water management agencies in California would do well to study the SCVWD blueprint as a model for their own management programs. Results of this study will be used by SCVWD to evaluate alternative management plans for the efficient use of surface, ground, and waste water and to evaluate the effects of various artificial recharge and ground water extraction strategies. In Santa Clara County and elsewhere, enlightened ground water basin management is essential to continued growth and welfare.

Ronald B. Robie

Ronald B. Robie, Director
Department of Water Resources
The Resources Agency
State of California

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State of California
Department of Water Resources
CALIFORNIA WATER COMMISSION

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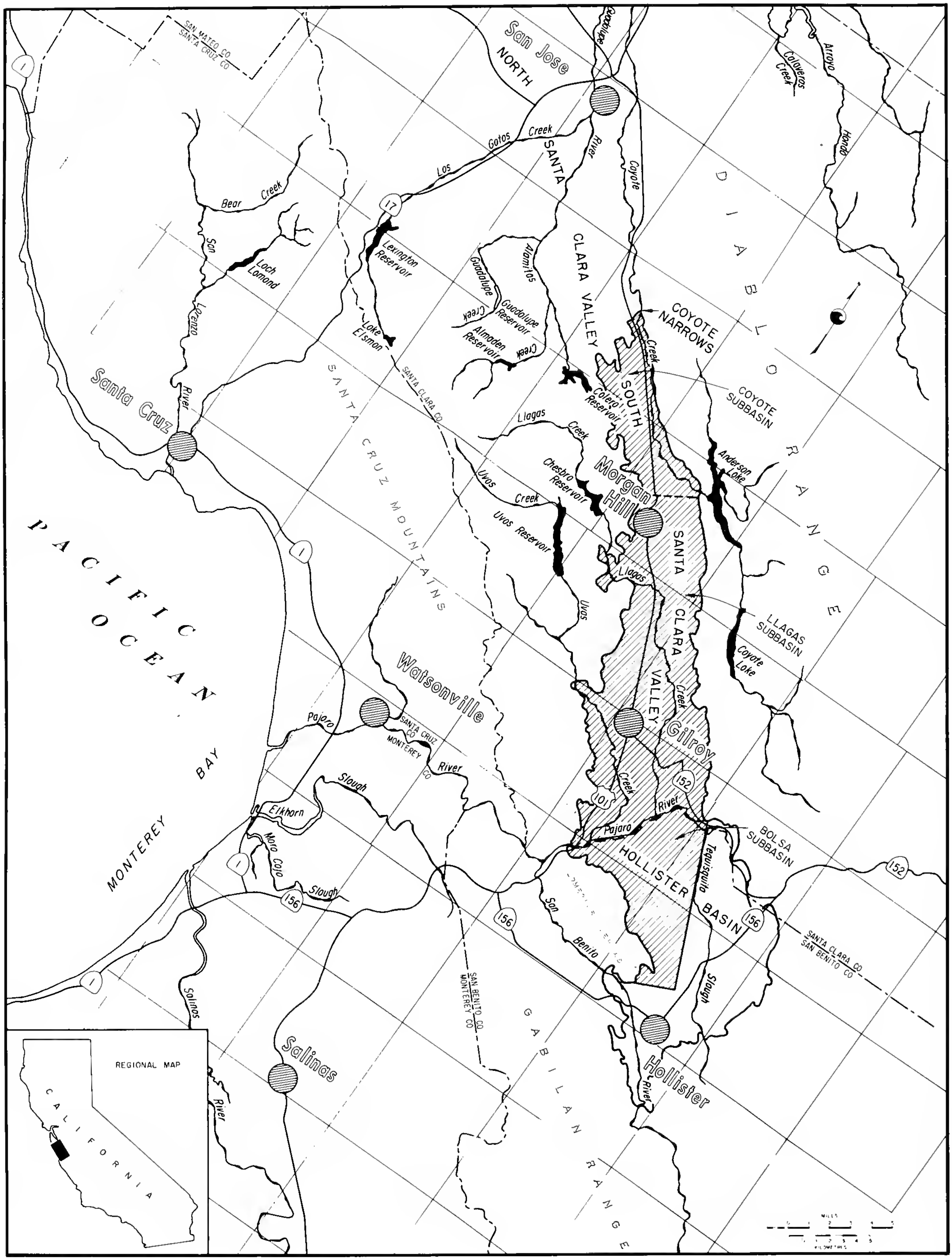


FIGURE 1.--Area of Investigation.

CHAPTER I. SUMMARY

Santa Clara County is a major water-consuming area which uses water supplied from surface storage reservoirs, ground water reservoirs, and imports. To obtain adequate information for the preparation of a series of water resource development plans in this area, the California Department of Water Resources (DWR) entered into an agreement with the Santa Clara Valley Water District (SCVWD) to study the water resources of Santa Clara County.

This bulletin, Volume IV of the Bulletin 118-1 series, "Evaluation of Ground Water Resources: South San Francisco Bay", presents the geohydrologic conditions that affect the occurrence and movement of ground water in South Santa Clara Valley and a contiguous portion of Hollister Basin in San Benito County. The cooperative agreement called for equal sharing of costs of the study within Santa Clara County, with the State providing the entire staff and funding for the San Benito County portion.

Plans have been drafted for additional studies of a wide range of management programs in the Santa Clara County portion of South Santa Clara Valley following the geohydrologic studies reported on in this bulletin. Parallel studies by DWR and SCVWD on possible use of waste water reclamation to extend the utility of present water supplies have been coordinated over the past several years and are continuing. In addition, a water quality management study has been conducted by the two agencies to provide information on cause-effect relationships and to form a basis for alternative water quality management plans.

Area of Investigation

The study area for this bulletin comprises South Santa Clara Valley, in Santa Clara County, and a portion of the contiguous Hollister Basin, in San Benito County. The area of investigation extends from Coyote Narrows, on the north, southward into San Benito County, as shown on Figure 1. The area is bounded on the west by the Santa Cruz Mountains and the Gabilan Range and on the east by the Diablo Range and the Calaveras fault. To the north, at Coyote Narrows, foothills of the Santa Cruz Mountains and Diablo Range nearly merge and form a constriction to ground water movement and, in turn, separate the study area from the remainder of the Santa Clara Basin to the north. The southern limit of the study area is formed by a narrow zone of water-bearing materials lying between the Calaveras fault, to the east, and the Lomerias Muertas, a group of Gabilan Range foothills to the west.

Identification of Coyote Narrows as the northern limit of South Santa Clara Valley differs from the northern limit of the valley as defined in State Water Resources Bulletin 7, "Santa Clara Valley Investigation", June 1955. The presently defined northern limit was determined to be more appropriate from a basin management point of view than is the Bulletin 7 boundary, which crosses water-bearing materials and is coincident with the topographic divide at Cochran Road, just north of Morgan Hill. This concept is valid even though both surface and ground water to the north of the divide move northward toward San Francisco Bay, and to the south of the divide move southward toward Pajaro River and Monterey Bay.

South Santa Clara Valley is composed of three subbasins: (1) Coyote subbasin, which extends from Coyote Narrows south to the topographic divide at Cochran Road; (2) Llagas subbasin, which extends from the Cochran Road topographic divide south to Pajaro River; and (3) Bolsa subbasin, which comprises the remainder of the study area.

Previous Investigations

Ground water has been a major source of water for domestic, agricultural, and municipal uses in South Santa Clara Valley for at least 90 years. Interest in this resource has resulted in the publication of a number of papers and reports dealing with this subject. The earliest known published reference to ground water in the South Santa Clara Valley was in a paper on the mineral resources of Santa Clara County by W. L. Watts, prepared for the Tenth Annual Report of the State Mineralogist in 1890. Watts discussed the ground water conditions throughout the county and made reference to an artesian zone southeast of Gilroy, in which "at a depth of 320 feet, a good flow of water was obtained, which flowed 5 inches above the edge of the 7-inch pipe".

In 1914, W. O. Clark began an extensive study of the ground water resources of the entire Santa Clara County area. Clark's work resulted in two publications by the U. S. Geological Survey. The earlier one, Water-Supply Paper 400, published in 1916, discusses geology and ground water conditions in the area from Coyote Narrows south to San Martin. The paper presents the location of 251 wells, logs of 72 wells, water levels from 207 wells, and a number of streamflow measurements.

Clark's second publication, Water-Supply Paper 519, published in 1924, discusses the geology and ground water conditions throughout the county as well as south to Hollister. The report shows locations of 466 wells in the present study area and also the limit of the zone of flowing wells as it existed in 1914.

An agreement between the State and Santa Clara Valley Water Conservation District was signed in 1930 to study that District's water resources. That study, published in 1933 as Division of Water Resources Bulletin 42, evaluated the ground and surface water hydrology of the county as far south as the Cochran Road topographic divide, which was the southerly boundary of the Water Conservation District at that time. The study identified 10 wells and also provided some water level and streamflow data. No attempt was made to identify or define any geologic conditions.

In 1948, a joint contract among the State, the County of Santa Clara, and the City of San Jose called for a new, detailed study of the ground water and surface water resources. The results of that study were published as State Water Resources Board Bulletin 7. The bulletin contained a general discussion of the geology and ground water resources of South Santa Clara Valley as well as that of the valley area to the north of Coyote Narrows. A map in that bulletin identified the Cochran Road topographic divide as being the boundary between South Santa Clara Valley and the ground water basin to the north.

Beginning in 1962, DWR undertook a comprehensive study of the geology and ground water resources of the entire South Bay portions of Alameda and Santa Clara Counties. This study has resulted in the publication of three bulletins dealing with the evaluation of ground water resources: two are concerned with the resources of southern Alameda County, and one with resources of the northern portion of Santa Clara County. This bulletin, on the resources of South Santa Clara Valley, completes the evaluation of ground water resources of the South Bay area.

Current Investigation

The geohydrologic study contained in this bulletin was performed to provide a framework for the development of a mathematical model of the ground water basin. The model, in turn, will be used as a conceptual tool for the generation of a workable ground water management plan.

Early in the study it became apparent that there was a critical need for geologic work to define the aquifer system which previously had been described as a heterogeneous mixture of permeable and impermeable strata. To this end, a statistical analysis was used to examine the large quantity of well logs and other subsurface data which were available. The results of the geologic phase of the study include the analysis which helped to develop a 3-dimensional concept of the subsurface features.

Major Findings

Nearly all of South Santa Clara Valley has underlying geologic formations which yield some water to wells. The water-bearing formations are faulted, and those faults traversing the valley floor appear to impede ground water movement to some degree. There is no indication of any total barriers to ground water movement except the Calaveras fault, which cuts across the San Benito County portion of the valley from San Felipe Lake to Hollister.

The area between Gilroy and Hollister contains lake deposits in the near-surface strata, causing confined ground water conditions to occur. Because of this condition, flowing wells were once prevalent in some parts of this area. There is some indication from preliminary modeling results that the water-bearing zones below the confining lake beds do not react as a totally confined aquifer system, but rather more like a leaky system. There appears to be some ground water infiltration taking place, implying that most of the lake beds are formed of discontinuous clay layers.

The ground water model for South Santa Clara Valley is verified as well as available data will permit. However, the level of verification still is not adequate for reliable analysis of detailed management and operation plans. Nevertheless, the model can be used as a tool for a general analysis of operation plans if its present limitations are recognized.

At the present time, there are two major differences between ground water levels generated by the model and historic levels:

1. Historic water levels in the upper part of the Llagas subbasin imply that an impulse recharge was introduced in 1969; hydrologic data calculations do not support this. Consequently, water levels generated by the model for this area do not agree with historic water levels for the period 1969 to 1971.

2. Historic water-level data for the central portion of the Llagas subbasin indicate a steep gradient; levels generated by the model have a more gradual gradient. This difference implies that some restriction to ground water migration might be taking place. The ground water monitoring network proposed in Chapter V, augmented by an improved data network, would provide the necessary data for further adjustment of the model.

Recommendations

Based on the material presented in this bulletin, it is recommended that the Santa Clara Valley Water District:

1. Complete verification of the ground water model developed in this study by:

    a. Redesigning the data collection system on the basis of geologic and hydrologic information.

    b. Testing the accuracy of the ground water model with the data collected during the first three to five years of operation of the redesigned data collection system.

2. Use the presently unverified model to test the general response of the ground water system for a variety of alternative conjunctive operation plans.

3. Continue to cooperate with other local water agencies in conjunctive operations of the surface and ground water resources available to the area.

4. Take measures to assure that overdraft does not recur by securing new sources of water as needed and obtaining necessary legal authority to prohibit damaging overdraft.

CHAPTER II. GEOLOGIC FEATURES

Decisions affecting the mode, occurrence, quality, and use of ground water in South Santa Clara Valley must be based on a knowledge of the geologic and hydrologic aspects of the study area and its surrounding region. The geology as it pertains to ground water can be perceived by examining the physiographic setting, the geologic history, and the nature and water-bearing characteristics of the various geologic formations.

Physiographic Setting

South Santa Clara Valley is a northwest-trending feature roughly 38 kilometres (km), or 24 miles (mi), in length; it ranges in width from 3 to 10 km (2 to 6 mi). Most of the valley is drained by the Pajaro River, which flows westerly along the southern boundary of the valley and empties into Monterey Bay, about 30 km (20 mi) to the west. Major tributaries include Llagas and Uvas Creeks, both of which enter South Santa Clara Valley from the west and flow southerly to the Pajaro River. The extreme northern portion of the valley is drained by Coyote Creek, which enters the valley 5 km (3 mi) northeast of Morgan Hill and flows northwesterly to exit at Coyote Narrows. Coyote Creek then continues 40 km (25 mi) northwesterly across North Santa Clara Valley and empties into San Francisco Bay. The floor area of South Santa Clara Valley covers about 180 square kilometres (km^2), or 70 square miles (mi^2). Of this area, 155 km^2 (60 mi^2) are within the Pajaro River drainage area with the remaining area drained by Coyote Creek.

The Hollister Basin is south of the Pajaro River, adjacent to South Santa Clara Valley, and wholly within San Benito County. This basin also is drained by the Pajaro River, with the major tributaries being Tequisquita Slough, Pacheco Creek, and the San Benito River. The study area portion of the Hollister Basin covers about 60 km^2 (23 mi^2). Hollister Basin is transected by the Calaveras fault, a regional feature that branches from the San Andreas fault 20 km (12 mi) southeast of the basin and, after crossing the basin floor, extends northerly through the foothills east of South Santa Clara Valley. Because of ground water barrier conditions along the fault, that portion of Hollister Basin east of the fault was excluded from the study area.

To the east of South Santa Clara Valley and Hollister Basin rise the foothills and mountains of the Diablo Range; promontories include Mt. Sizer, elevation 983 metres (3,225 ft), Mariposa

Peak, elevation 1 055 m (3,461 ft), and Laveaga Peak, elevation 1 159 m (3,802 ft). To the west, north of the Pajaro River, are the Santa Cruz Mountains, with Loma Prieta, elevation 1 160 m (3,806 ft) and Mt. Madonna, elevation 578 m (1,896 ft) being the principal promontories. South of the Pajaro River is the Gabilan Range, culminating at Fremont Peak, elevation 967 m (3,172 ft). Also to the west of Hollister Basin are the Lomerias Muertas, which attain a maximum elevation of 360 m (1,181 ft).

The floor of South Santa Clara Valley attains a maximum elevation along the drainage divide near Morgan Hill. Here the elevation is 145 m (476 ft) near the east side of the valley at a point immediately southwest of Anderson Dam. The lowest point is at an elevation of 35 m (115 ft) where the Pajaro River exits the valley. Coyote Creek leaves the valley at Coyote Narrows at an elevation of 75 m (246 ft).

The study area portion of Hollister Basin is a low-lying, extremely level area called The Bolsa. This intensely farmed area slopes gently upward from the Pajaro River, at elevation 35 m (115 ft), to elevation 76 m (250 ft) at the southern boundary of the study area.

Geologic History

The geologic history of South Santa Clara Valley can be traced to the latter part of the Jurassic Period, some 140 million years ago, as shown on Figure 2. Prior to that time, the history is largely known only by inference, as the record has been obscured by events of Jurassic and later periods. During the Jurassic and Cretaceous Periods, much of this part of California was dominated by a marine environment. Sediments accumulated on the ocean floor associated with outpourings of oceanic volcanic rocks and injection of serpentine along zones of weakness. These rocks, now folded, altered, and deformed, comprise the Franciscan Formation now exposed in the Santa Cruz Mountains. To the east, sequences of nonvolcanic sands and clays also were deposited on the ocean floor with the resulting rocks now constituting the Great Valley Sequence which crops out to the east of South Santa Clara Valley.

For the next 40 million years, the region was lifted above sea level, deformed by faulting and warping, and subjected to erosion. Beginning in the Miocene Epoch, about 25 million years ago, a portion of the area again became submerged and deposition of marine clays and sands resumed. These latter materials now form the Tertiary marine sediments found to the west of Gilroy.

Near the close of the Miocene Epoch, much of the area again was uplifted and faulted over a period of about 2 million years, until the early part of the Pliocene Epoch, when marine deposition resumed. At that time, vast amounts of sand were deposited in the area from Lomerias Muertas west to Monterey Bay, creating what is now the Purisima Formation. Once again the land was uplifted above sea level and further deformed by erosion and faulting.

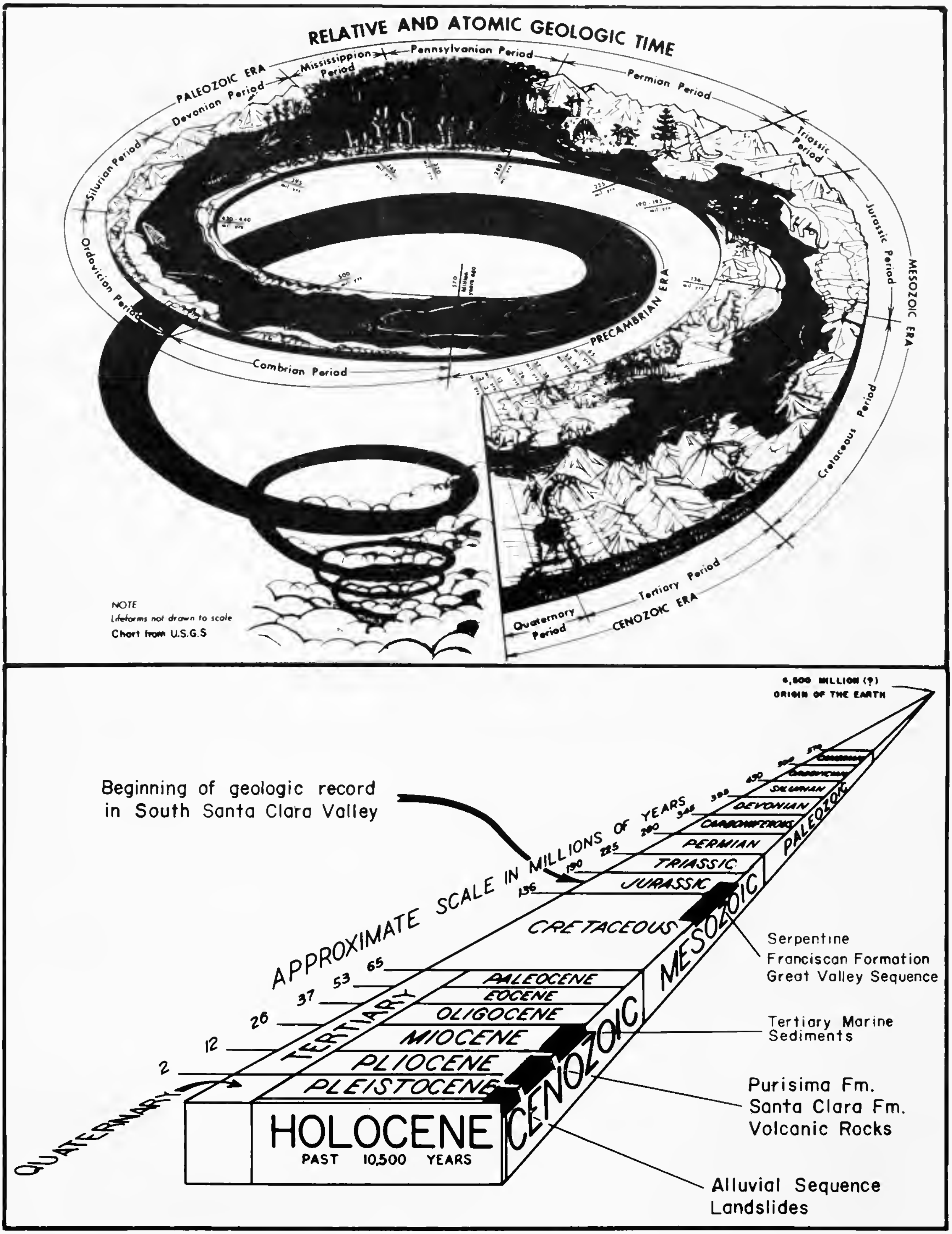


FIGURE 2.--Looking Back in Geologic Time.

Continental sedimentation began in the southern part of the area about 4 million years ago, followed some time thereafter by volcanic activity which broke out in the vicinity of the Calaveras fault and produced the series of basalt flows now found east of Gilroy. The volcanic activity was associated with deposition of great thicknesses of continental clay, sand and gravel, forming the Santa Clara Formation. Deposition of the Santa Clara Formation continued throughout much of the Pleistocene Epoch, during which there was continued regional faulting and folding.

During the latter part of the Pleistocene, movement along the San Andreas fault, to the west, apparently formed a natural dam and created a lake that filled both South Santa Clara Valley and Hollister Basin to a maximum elevation of 90 m (295 ft). This lake, named Lake San Benito, apparently was not the first lake to occupy the area, as old dissected terraces suggest that there has been at least one earlier lake with a water surface elevation of about 130 m (427 ft). Lake San Benito was in existence for a fairly long time, indicated by a maximum thickness of lake-bottom clays on the order of 75 m (246 ft). At times, Lake San Benito probably spilled to the north and drained to the sea by way of the depression that is now San Francisco Bay. At other times, the lake drained to the west through what is now Elkhorn Slough. This westerly drainage is believed to have contributed to the excavation of the well known Monterey Sea Canyon. Ultimately, fault movement removed the natural blockage, and Lake San Benito was drained. However, once again, fault movement associated with landsliding apparently blocked the outlet and a later lake, called Lake San Juan, was created with a water surface elevation of 60 m (197 ft). An additional 50 m (165 ft) of lake-bottom sediments accumulated in Lake San Juan before it too was drained, leaving the area much as it is today.

Geologic Formations and Their Water-Bearing Properties

A number of geologic formations in South Santa Clara Valley and Hollister Basin yield water to wells to some degree. The Pliocene to Holocene materials are the principal water-producing units; water derived from these materials usually is of excellent quality, although local quality problems occur. In contrast, the pre-Pliocene rocks yield little water and the water may contain enough undesirable mineral constituents to make it unusable for most beneficial purposes.

Each of the various geologic formations occurring in the South Santa Clara Valley area is briefly discussed below. The discussion includes a description of the general lithology, the water-yielding characteristics, and the general character of the water quality. Table 1 presents a brief description of the general character and water-bearing properties of the various geologic formations. The areal extent of each of the various geologic units is shown in Figures 3A, 3B, and 3C; geologic sections are shown in Figures 4A through 4D.

Table 1. Description of Geologic Units, South Santa Clara Valley-Hollister Basin Area

Geologic Age	Geologic Unit	Map Symbol (Figure 3)	General Character, Location, and Thickness	Water-bearing Properties
Holocene	Landslides	Qls	Unstable masses of clay and rocks occurring on slopes east of Valley; may be as much as 15 m (50 ft.) thick.	Not a reliable source of ground water; locations of a number of springs and seeps.
	Stream Deposits	[illegible]	Unconsolidated gravel and sand in and near stream channel areas and on terraces; may be subject to flooding. May be as much as 15 m (50 ft.) thick.	May be good source of ground water in nonflooding areas; ground water is unconfined. Most ground water in this unit is underflow.
	Basin Deposits	Qb	Unconsolidated clay, silt and organic materials occurring in flat, undrained portions of Valley; saline soils are present in some areas. May be subject to ponding. May be as much as 30 m (100 ft.) thick.	Very low permeability; not a reliable source of ground water. Of no importance to ground water recharge.
	Younger Alluvium	Qy	Unconsolidated floodplain deposits of clay, silt, and sand; contains some zones of sandy gravel. May be as much as 30 m (100 ft.) thick.	Provides water to shallow wells. Important to ground water recharge. Ground water is generally unconfined.
	Alluvial fans	Qf	Unconsolidated to semiconsolidated sand, gravel, and clay occurring at edge of valley and at mouths of tributaries. May be as much as 37 m (125 ft.) thick. Deposits of clayey gravel underlying older alluvium probably belong to this unit.	Generally yields large amounts water to properly-constructed wells. Most ground water is under some degree of confinement.
Plio-Pleistocene	Older Alluvium	Qo	Unconsolidated older floodplain deposits of clay, silt, and sand with predominant clay subsoil. May be as thick as 37 m (125 ft.) near the axis of the valley.	Provides some water to wells; most wells located on this unit produce water from underlying materials. Ground water varies from unconfined to confined.
	Santa Clara Formation	TQs	Folded and faulted beds of consolidated silt, clay, and sand; occasional zones of gravel. Exposed to east of valley; occurs at depth under valley floor. Up to 550 m (1,800 ft.) of stratigraphic thickness.	A major water-bearing formation. Many deep wells in valley areas tap upper part of this formation, yielding large quantities of good quality water.
	Volcanic rocks	TQv	Basalt and basic intrusives occurring in hills to east of valley. Occur interbedded with Santa Clara Formation; present in subsurface beneath floor of valley. Thickness not known.	Of little importance to ground water.
Pliocene	Purisima Formation	Tp	Folded and faulted beds of massive micaceous siltstone, sandstone, conglomerate, and gypsiferous shale cropping out west of Hollister Basin; occurs at depth beneath some valley floor areas. Stratigraphic thickness is as much as 4 600 m (15,000 ft.); most of formation is of marine origin.	Uppermost 600 m (2,000 ft.) contains good quality water under confined conditions; remainder of formation contains saline water.
Miocene	Tertiary Marine Sediments	Tm	Fossiliferous conglomerate and sandstone; siliceous shale and mudstone. All are of marine origin. Exposed in hills west of Gilroy. Of undetermined thickness.	Generally contains saline water. A few low-yielding wells tap potable water contained in fractures and flushed zones.
Cretaceous	Great Valley Sequence	K	Folded, thinly-bedded shale, sandstone, and conglomerate; all of marine origin. Estimated thickness 12 000 m (40,000 ft.)	Contains saline and mineralized water.
Jura-Cretaceous	Franciscan Formation	JKf	Folded, faulted, and sheared lithic sandstone and shale; altered basalt, diabase, and tuff; chert, greenstone, limestone, and melange. All of marine origin. Estimated thickness 15 000 m (50,000 ft.)	Of no significant importance to ground water.
	Ultrabasic rocks	ub	Green to black serpentine. Of undetermined thickness.	Of no importance to ground water.

Franciscan Formation

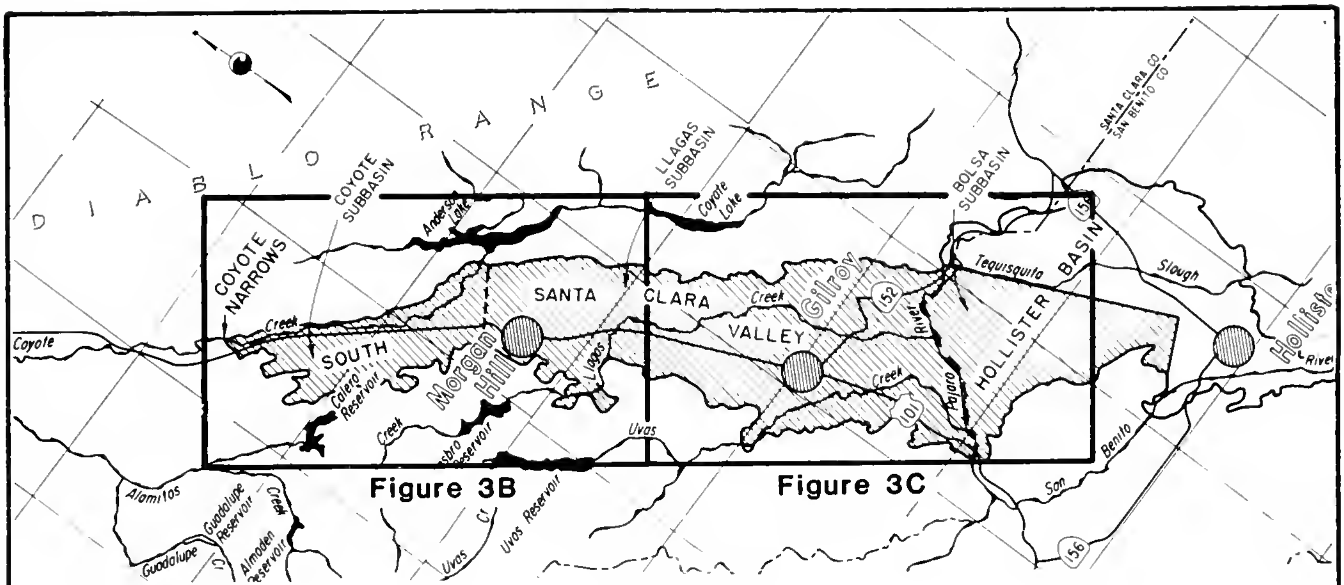
Rocks of the Franciscan Formation are exposed in the Santa Cruz Mountains to the west of South Santa Clara Valley, at several isolated hills protruding through the valley floor, at a few locations in the foothills immediately east of the valley, and in the central portion of the Diablo Range. The formation also underlies South Santa Clara Valley and Hollister Basin at depths ranging from 50 m (160 ft) near Coyote to as much as 1 000 m (3,000 ft) in The Bolsa.

The Franciscan Formation has been estimated by Bailey and others (1964) to be about 15 000 m (50,000 ft) in stratigraphic thickness. It is composed of a great variety of folded, faulted, and sheared marine sediments and related oceanic volcanic rocks. The most widespread rock type is a well indurated, poorly sorted sandstone containing abundant grains of quartz and feldspar as well as many lithic fragments; this rock type frequently has been called a graywacke. The predominant color of the sandstone is gray; weathered exposures commonly are tan to brown. Exposures of the sandstone are usually mantled by a residual soil cover about one metre (3 ft) thick.

Shale accounts for about 10 percent of the volume of the Franciscan Formation. It is commonly interbedded with the sandstone and is usually gray to black. Volcanic rocks, such as pillow basalt, diabase, tuff, and tuff breccia are common in most areas; many of these rocks have been altered to greenstone. Minor rock types include chert, limestone, silica-carbonate rock, and melange, the latter being a chaotic mixture of sandstone, greenstone, chert, and other rocks in a sheared, shaly matrix.

Bedding in the Franciscan Formation is highly variable, with individual beds ranging from 2.5 centimetres (1 in.) to 6 metres (20 ft) in thickness. Fossils generally are rare, although locally abundant in beds of chert and limestone. The Franciscan Formation is of marine origin and was probably formed in the deep ocean in water depths ranging from 180 to 900 m (600 to 3,000 ft).

The Franciscan Formation is considered to be of no significant importance to ground water. In the entire South Santa Clara Valley area there are only 25 wells which are known to yield water from this formation and for which data are available. The wells range in depth from 30 to 100 metres (100 to 330 ft), and the depth to water at the time of drilling ranged from 4 to 55 metres (13 to 180 ft). Discharges from all of these wells are minimal, ranging from 10 to 190 litres per minute (L/m), or 3 to 50 gallons per minute (gpm). Any ground water yielded from the Franciscan Formation is derived from secondary fractures rather than from primary openings. Water quality data are lacking from these wells. Because the wells are all used for domestic purposes, it can be assumed that the water is of acceptable quality.



INDEX MAP

SYMBOLS

GEOLOGIC CONTACT, BEDROCK UNITS

GEOLOGIC CONTACT,ALLUVIAL UNITS

LANDSLIDE

FAULT, SHOWING DIRECTION OF MOVEMENT;
DASHED WHERE PROJECTED,
DOTTED WHERE CONCEALED.

APPROXIMATE LIMIT OF LAKE SAN BENITO
(Water-Surface Elevation 90 m)

APPROXIMATE LIMIT OF LAKE SAN JUAN
(Water-Surface Elevation 60 m)

LOCATION OF GEOLOGIC SECTION

Note: SeeTable 1 For Description Of Geologic Units

SOURCES OF DATA

BEDROCK GEOLOGY:
T. W. Dibblee (1973),
C. Kilburn (1972),
T. H. Rogers and J. W. Williams (1974)

LANDSLIDES:
T. H. Nilsen (1972)

ALLUVIAL GEOLOGY:
D. Isgrig (1969),
W. C. Lindsey (1974)

FIGURE 3A.--Areal Geology, South Santa Clara Valley.

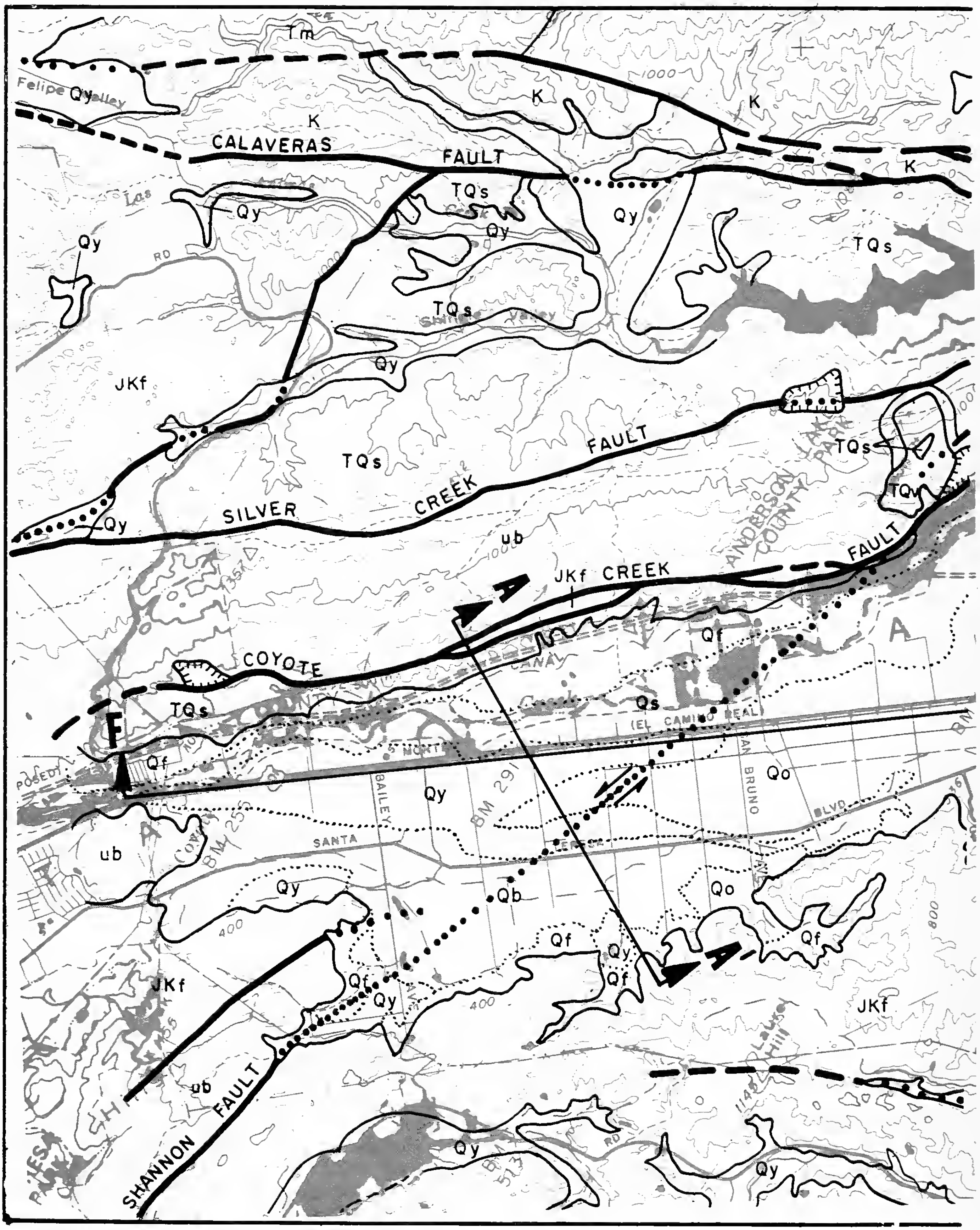
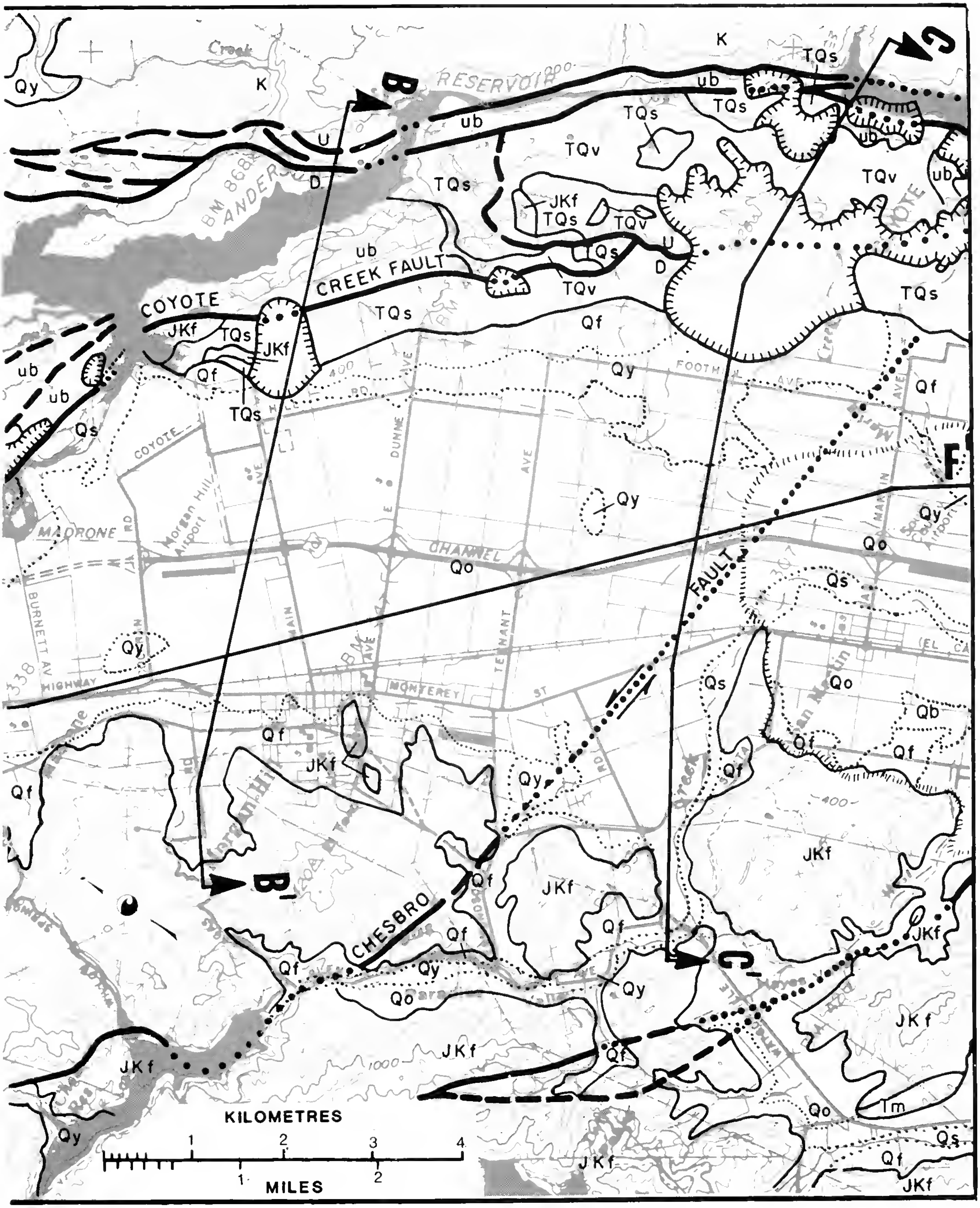


FIGURE 3B.--Areal Geology,



South Santa Clara Valley.

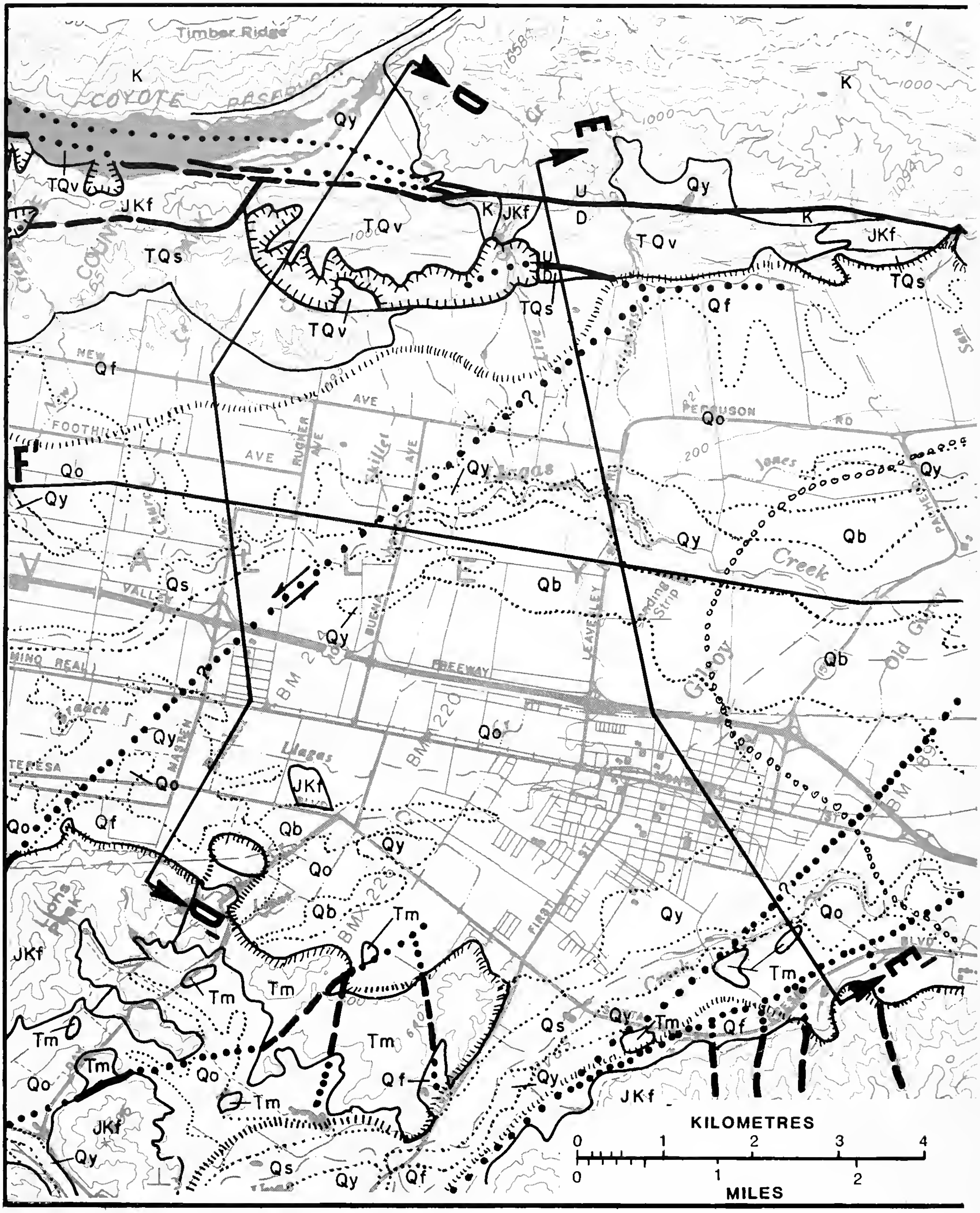
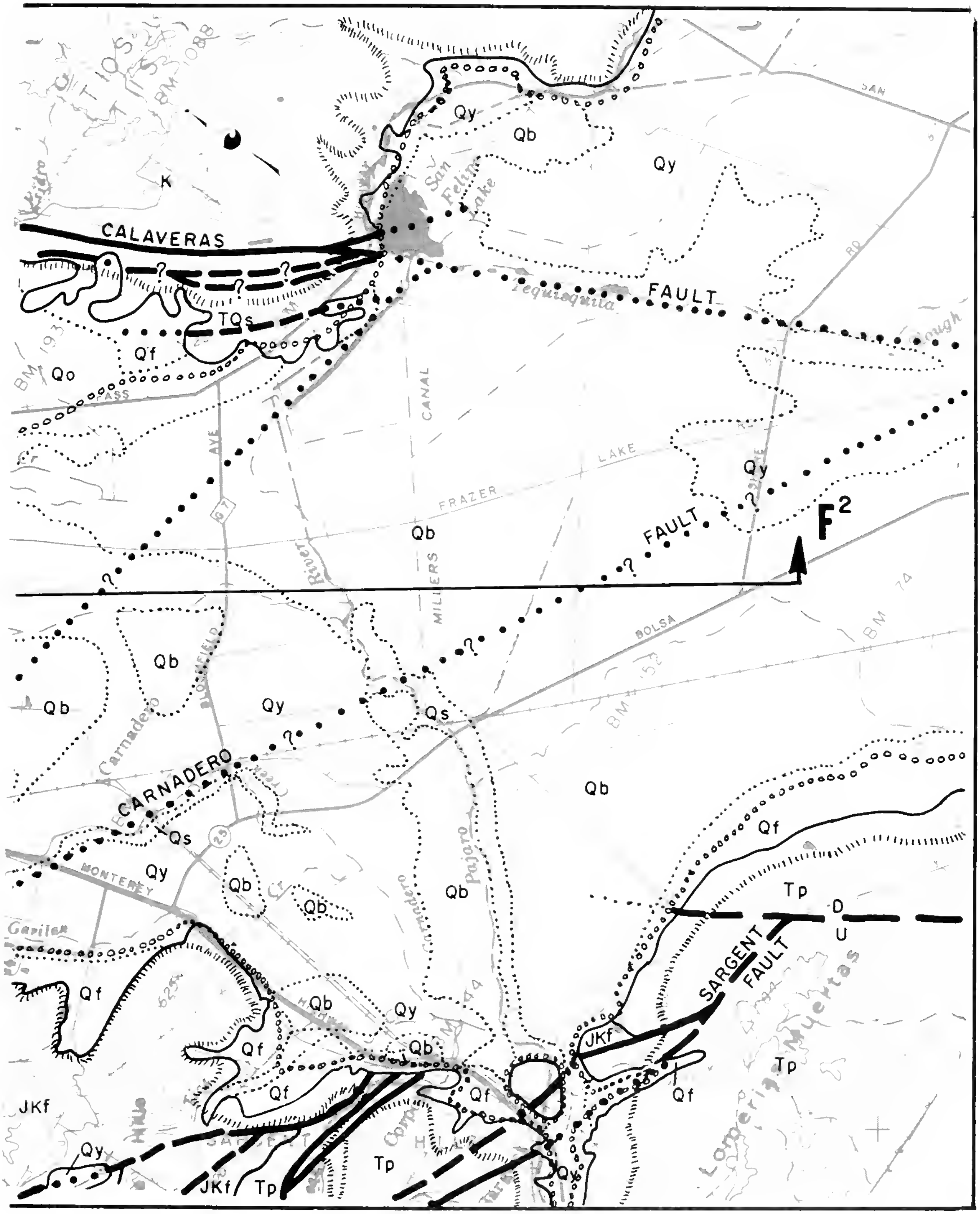
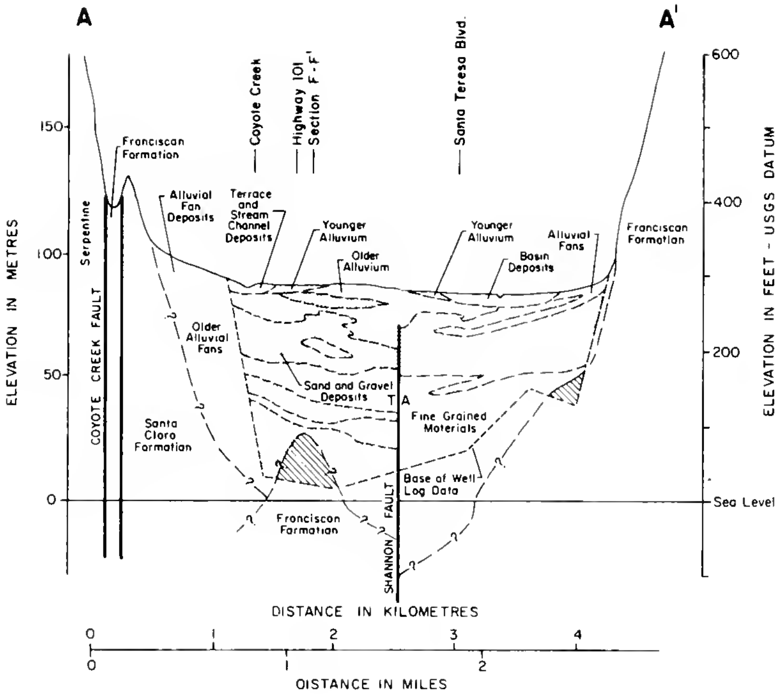


FIGURE 3C.--Areal Geology,



South Santa Clara Valley.



NOTE: See Figure 3B for locations of section.

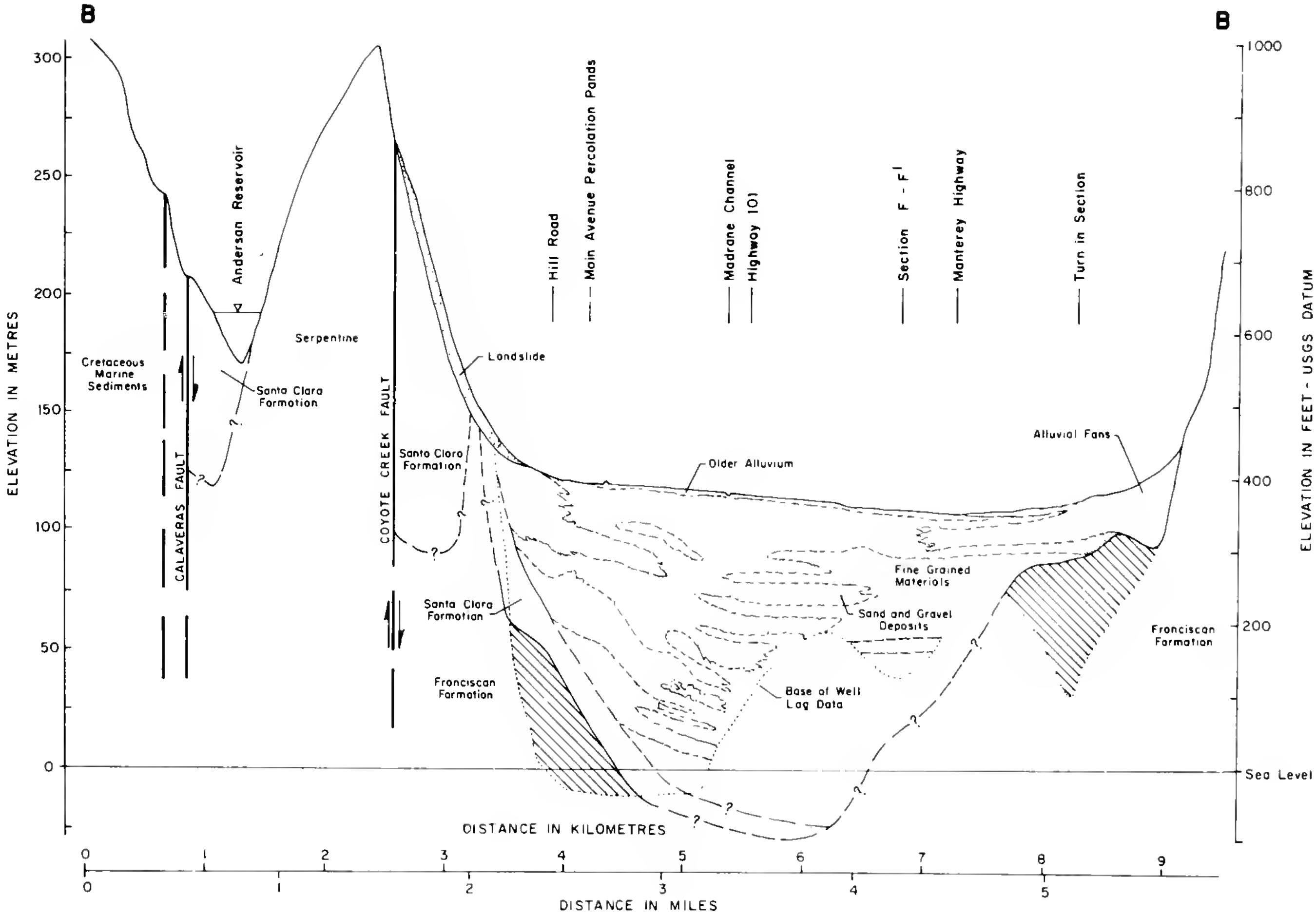


FIGURE 4A.--Geologic Sections A-A' and B-B', South Santa Clara Valley.

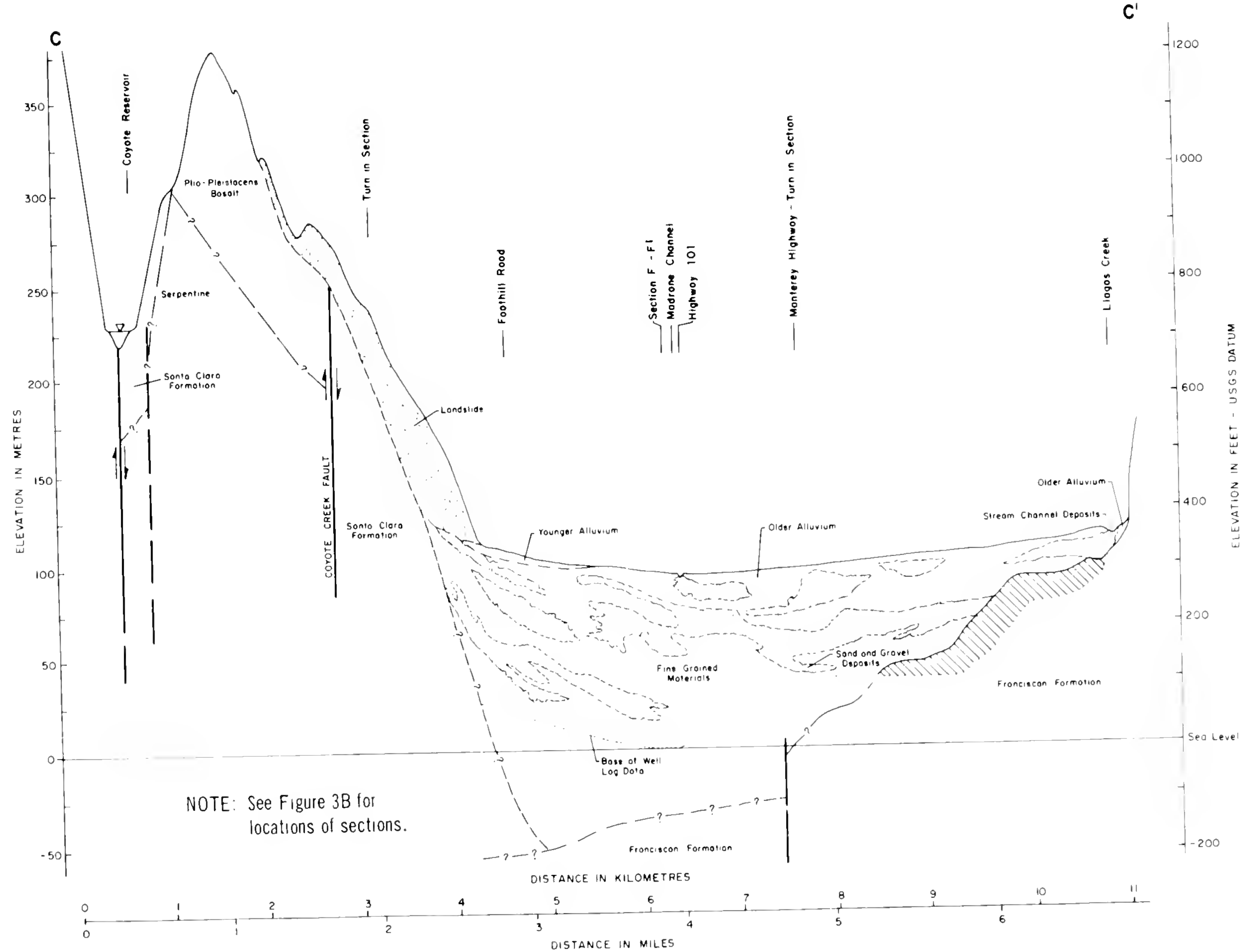
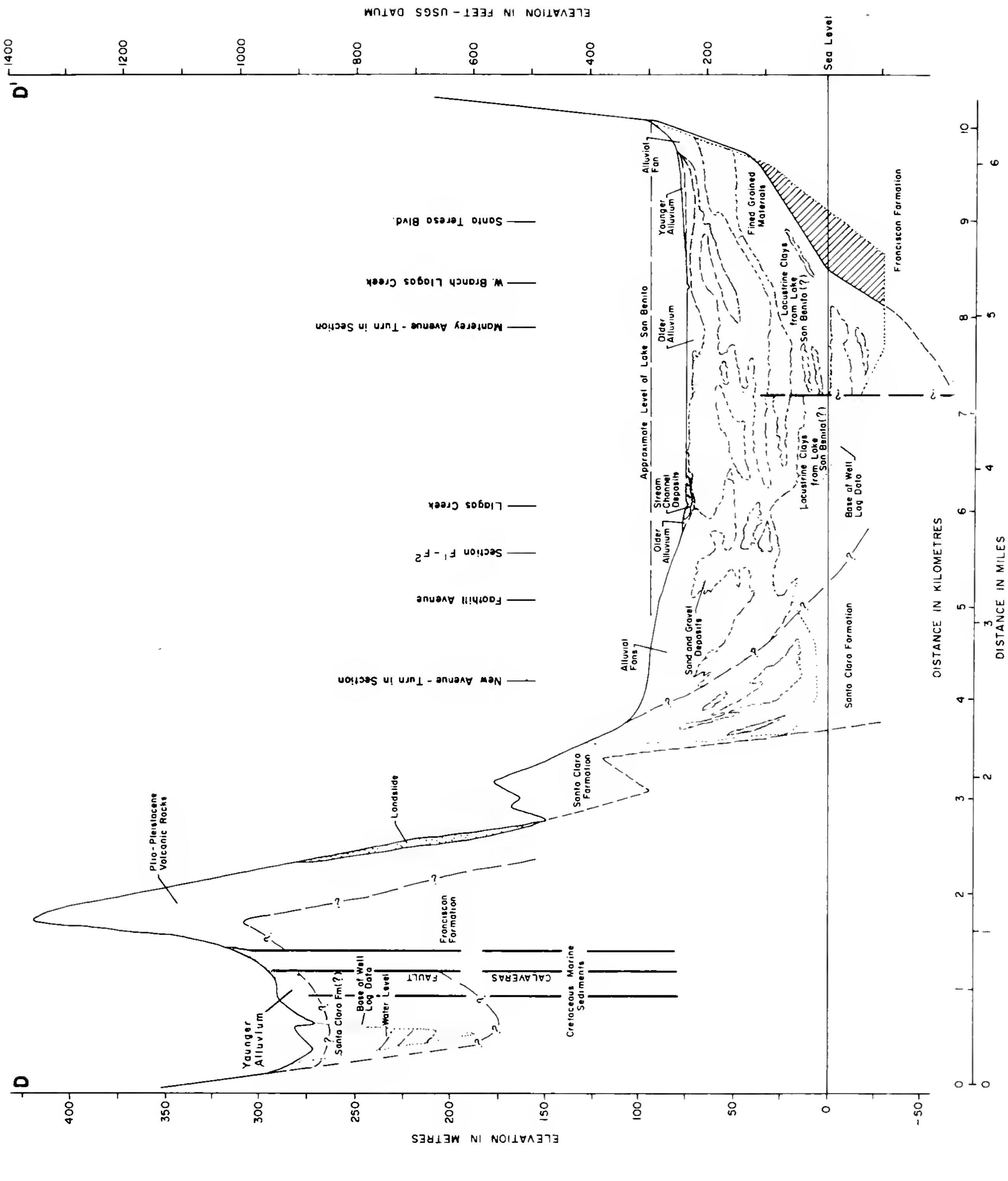


FIGURE 4B.--Geologic Section C-C', South Santa Clara Valley.


D
D'
ELEVATION IN FEET - USGS DATUM
ELEVATION IN METRES
DISTANCE IN KILOMETRES
DISTANCE IN MILES
Sea Level
Santa Teresa Blvd.
W. Branch Llagos Creek
Monterey Avenue - Turn in Section
Llagos Creek
Section F' - F²
Foothill Avenue
New Avenue - Turn in Section
Approximate Level of Lake San Benito
Alluvial Fan
Younger Alluvium
Older Alluvium
Stream Channel Deposits
Alluvial Fans
Sand and Gravel Deposits
Fined Grained Materials
Lacustrine Clays from Lake San Benito (?)
Base of Well Log Data
Franciscan Formation
Santa Clara Formation
Landslide
Plio-Pleistocene Volcanic Rocks
Younger Alluvium
Santa Clara Fm(?)
Base of Well Log Data
Water Level
CALAVERAS FAULT
Cretaceous Marine Sediments

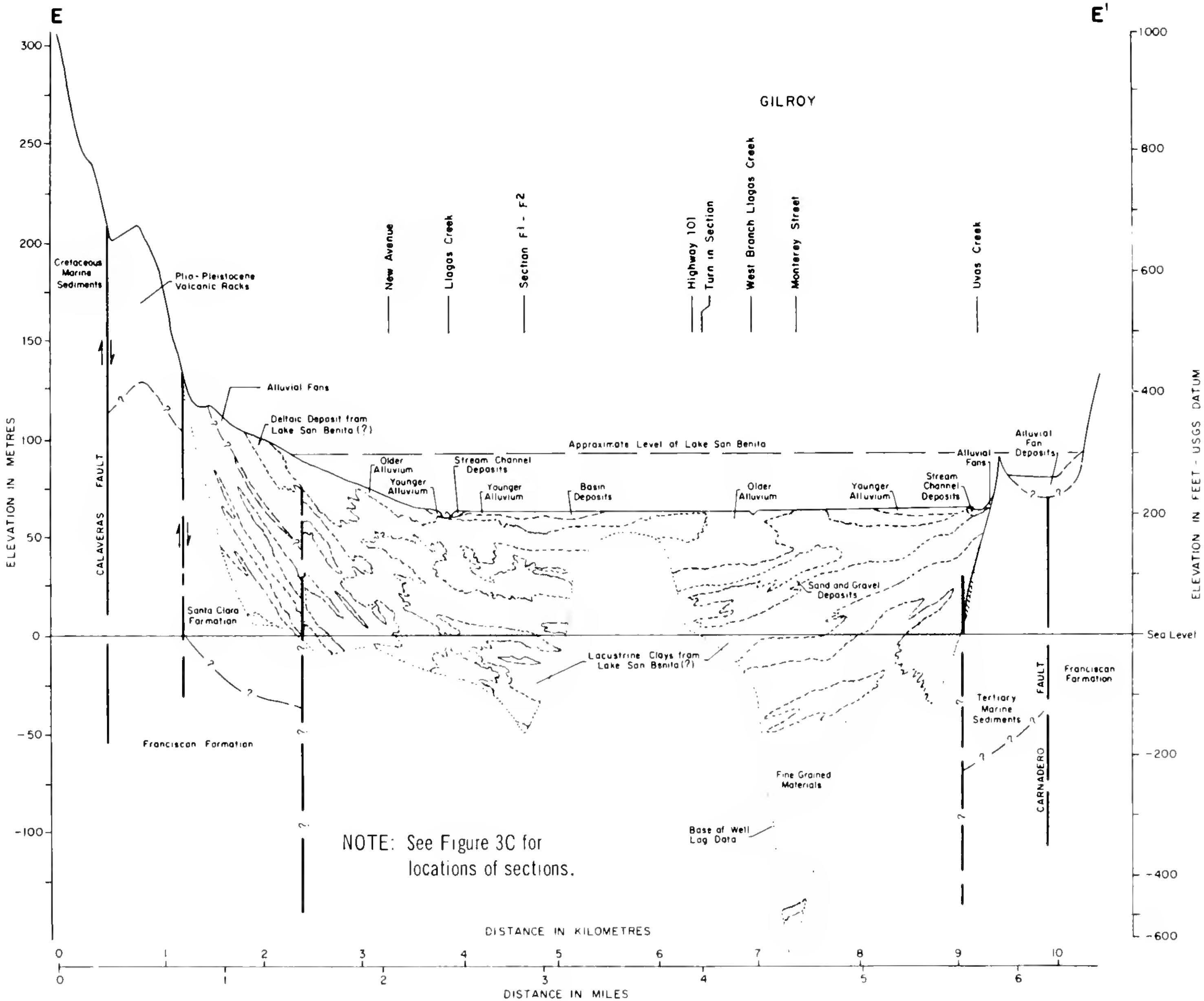


FIGURE 4C.--Geologic Sections D-D' and E-E', South Santa Clara Valley.

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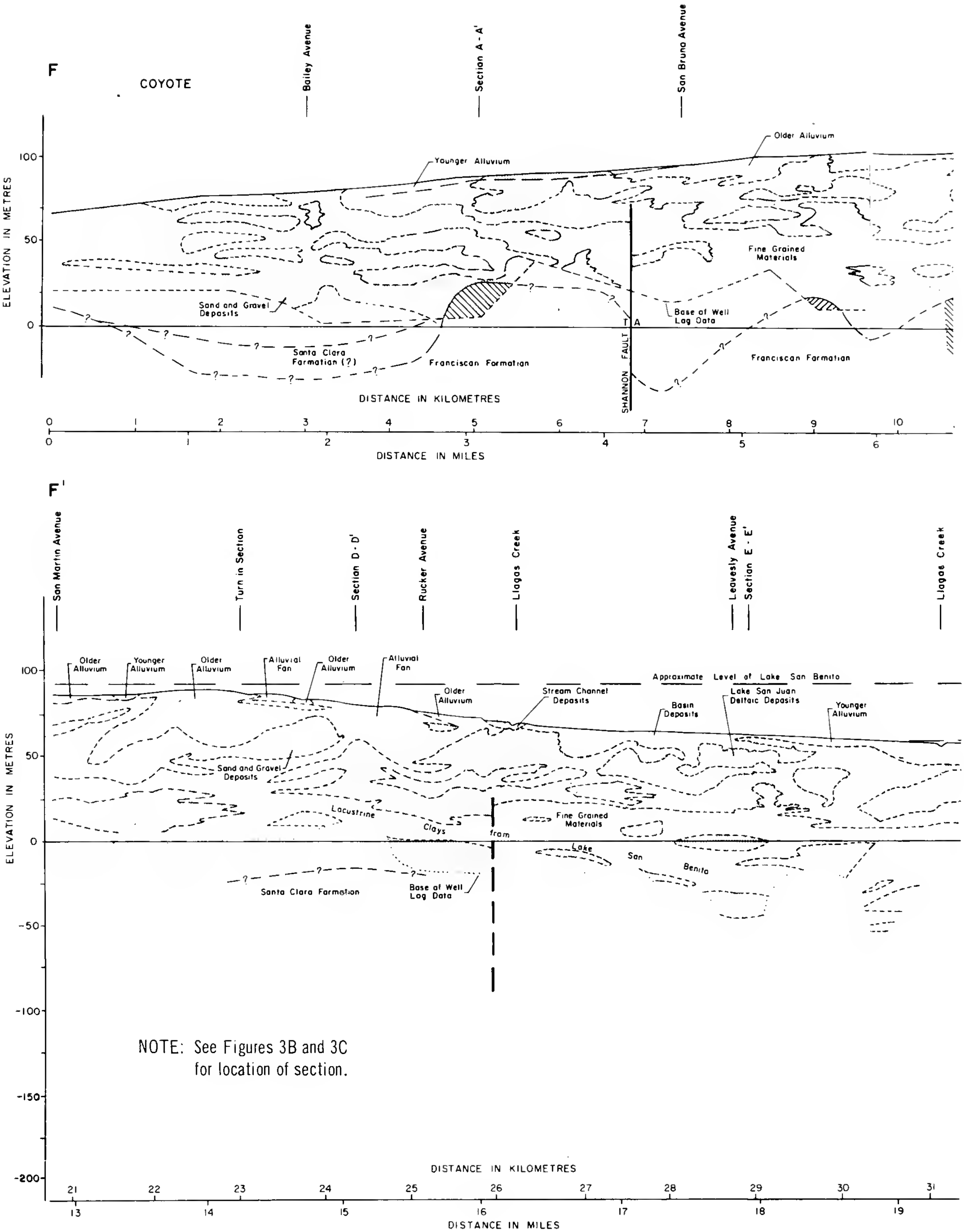
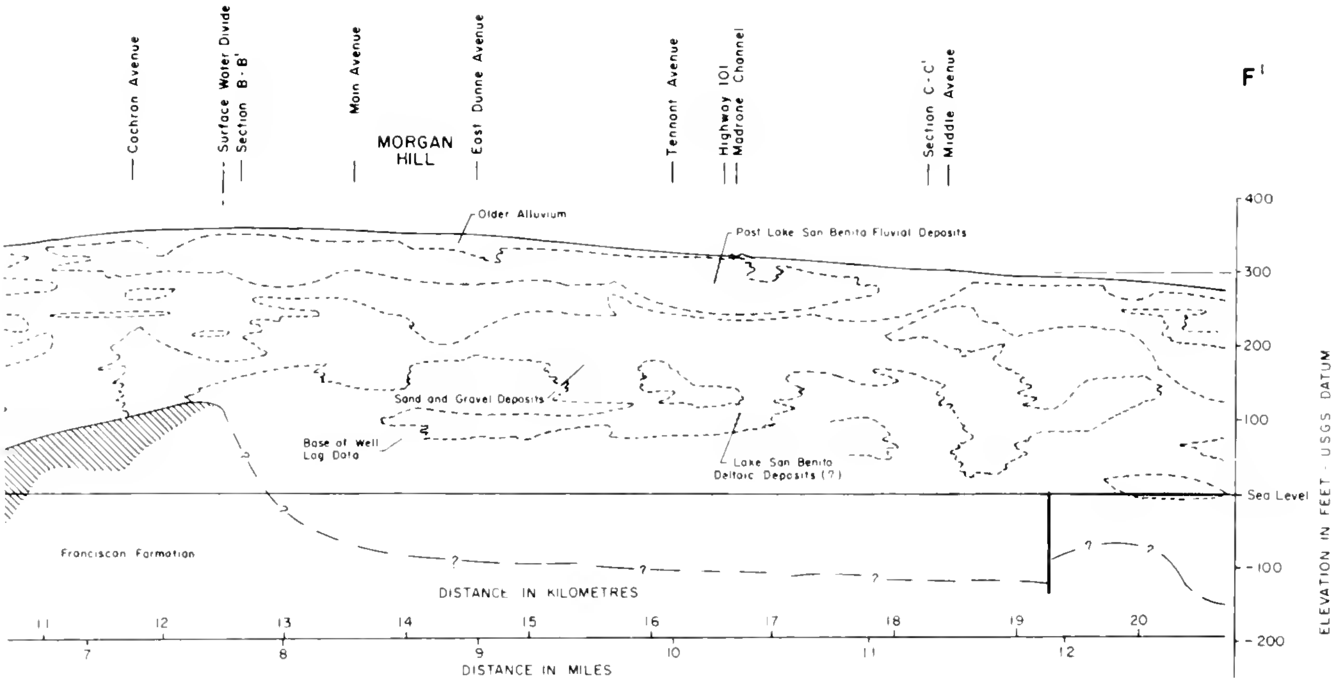
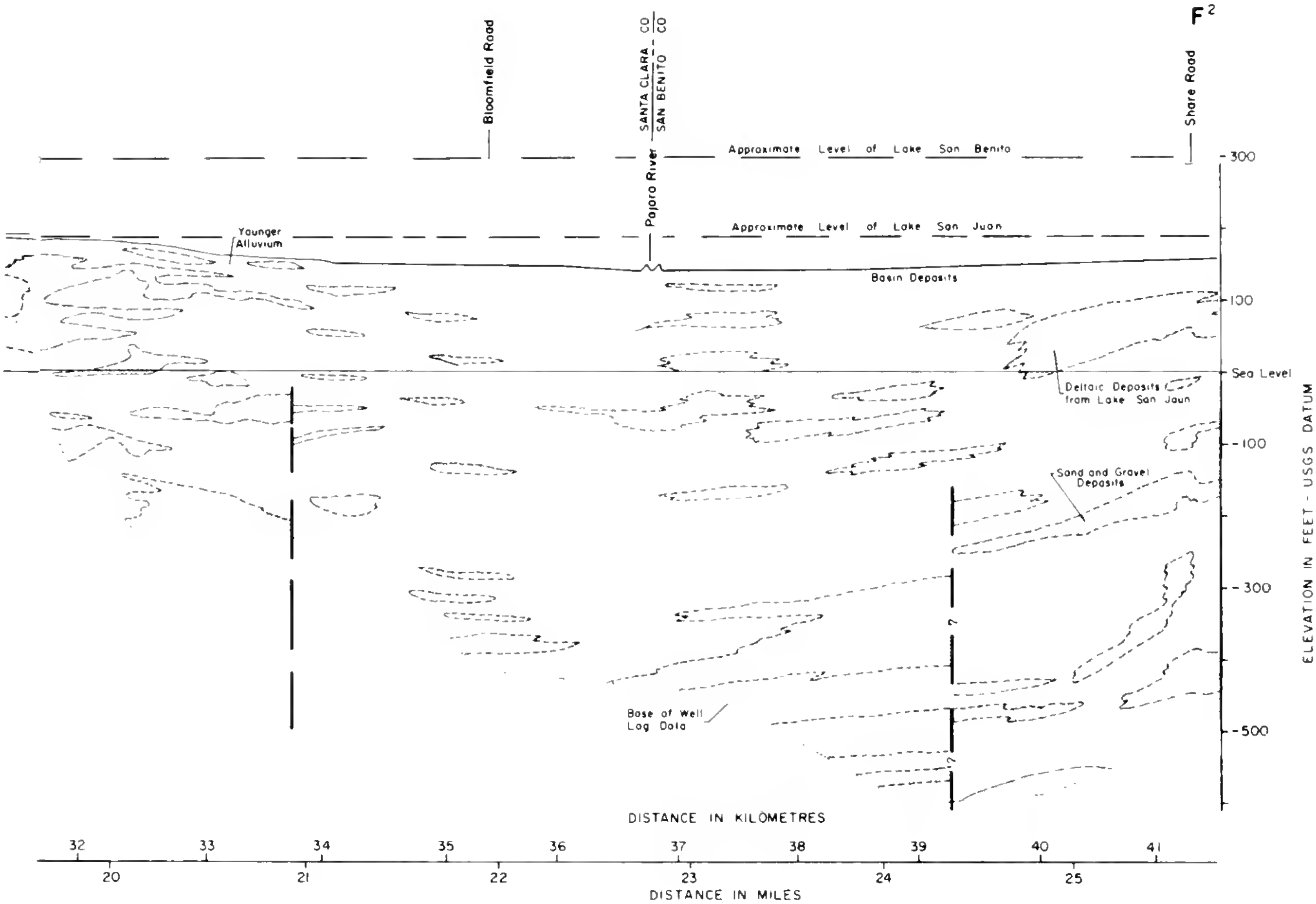


FIGURE 4D.--Geologic Section F-F^1-F^2,





South Santa Clara Valley.

Ultrabasic Rocks

Ultrabasic rocks, which belong to the Franciscan Formation, crop out near Coyote Narrows, in the hills east of Coyote Creek, and at other locations in Franciscan terrain. These rocks also occur at depth beneath alluviated areas in association with Franciscan rocks. The ultrabasic rocks are of undetermined thickness and are composed principally of green to black serpentine which exhibits a reddish-brown soil cover. The serpentine is usually extensively fractured and sheared. No known wells tap these rocks, and it is not expected that they would yield measurable quantities of water to wells. Water quality data are not available, but ground water contained in ultrabasic rocks in other regions is generally of poor quality.

Great Valley Sequence

Rocks of the Great Valley Sequence, of Cretaceous age, crop out to the east of South Santa Clara Valley in a belt that is about 5 km (3 mi) wide between the Calaveras fault on the west and the Madrone Springs fault on the east. These rocks also are exposed to the east of Hollister Basin as well as at certain localities in the Santa Cruz Mountains. The rocks of the Great Valley Sequence differ markedly from those of the Franciscan Formation. Sandstones tend to be clean and of uniform grain size; calcite cement is present locally. Shales are abundant and locally form more than one-half of the sequence. Conglomerate is generally present and may occur in very thick lenses. The total estimated thickness of the Great Valley Sequence is about 12 000 m (40,000 ft). The Great Valley Sequence is thinly bedded; rhythmic alterations of sandstone and shale are common; beds generally have great continuity. Unlike the Franciscan Formation, fossils are common to locally abundant. Also unlike the Franciscan Formation, the rocks of the Great Valley Sequence are only moderately to slightly deformed. All of the sequence is of marine origin, having been deposited in a nonvolcanic environment at depths significantly less than the deep ocean environment of the Franciscan Formation.

Well data are totally lacking for the Great Valley Sequence. Wells drilled into these rocks would probably yield minimal amounts of water and the incidence of dry holes would be very high. Ground water contained in fractures in these rocks probably is of adequate quality, although areas of mineralized or saline water are known to occur throughout the sequence.

Tertiary Marine Sediments

Exposures of marine sediments of Miocene age are found to the west of Gilroy, in the area from Day Road south to Uvas Creek. The sediments consist of a sequence of fossiliferous conglomerate and sandstone belonging to the Temblor Formation, overlain by hard

brown siliceous shale and mudstone belonging to the Monterey Formation. These sediments are of undetermined thickness.

Like the older marine sediments, these materials are not considered to be of any great significance as sources of ground water. Only four wells are known to yield water from the Tertiary Marine Sediments, and they produce only about 15 to 60 L/m (4 to 16 gpm). The four wells range in depth from 50 to 90 metres (165 to 295 ft), and the depth to water at the time of drilling was about 15 metres (50 ft). Although no water quality data are available from these wells, the water produced is probably only marginally potable. The water derived from these sediments is probably contained in such secondary openings as fractures and shears; some potable water also may be derived from flushed zones. Because of the marine origin of these sediments, most water contained in primary openings may be expected to be saline.

Purisima Formation

The Purisima Formation, of Pliocene age, is of nonmarine and marine origin; it contains many zones of fresh water. The formation is exposed to the southwest of South Santa Clara Valley and Hollister Basin. It also underlies the valley floor south of Gilroy at an undetermined depth.

The lowermost member of the formation is exposed in the Sargent Hills and Lomerias Muertas from Tick Creek southward. The member is composed of sandstone with interbedded micaceous siltstone and is estimated to have a stratigraphic thickness of about 1 500 to 2 100 m (4,920 to 6,890 ft). The member is folded and faulted, and of medium permeability. Kilburn (1972) reports that ground water in this member is saline.

The middle member of the formation is exposed principally in the central portion of Lomerias Muertas. It has a stratigraphic thickness of not over 1 500 m (4,920 ft) and is composed of massive sandstone, pebbly conglomerate, and gypsiferous shale. Kilburn states that this member probably contains poor quality saline water at depth, but shallow depths probably contain potable water. Ground water in this member may locally contain large concentrations of sulfate, and it may be under some degree of confinement.

The uppermost member of the Purisima Formation also is exposed in the Lomerias Muertas. The member consists mostly of pebbly sandstone and is estimated to be about 600 to 1 000 metres (2,000 to 3,300 ft) in stratigraphic thickness. Most of the materials in this member are of continental origin. A few wells are known to tap this member, but well data are totally lacking.

Kilburn reports that the member contains good quality ground water under confined conditions and yields large amounts of water to wells.

Santa Clara Formation

Sediments belonging to the Santa Clara Formation, of Plio-Pleistocene age, are exposed in the hills bordering much of the east side of South Santa Clara Valley; related materials are exposed farther to the east. The formation also underlies much of South Santa Clara Valley, but the depth to the uppermost layers of the formation could not be determined because it is not possible to make a distinction between it and the overlying alluvial deposits from data presented on water well drillers' logs.

The Santa Clara Formation consists of fairly well consolidated silt, clay, and sand; some zones of gravel are present. Most of the materials were deposited under fluvial conditions. The formation is in fault contact with or lies unconformably on a fairly rugged surface of older rocks, notably those of the Franciscan Formation and Great Valley Sequence. After deposition, the formation was folded into northwest-trending anticlines and synclines whose limbs dip from 5 to 40 degrees. The Santa Clara Formation has an estimated maximum stratigraphic thickness of 550 metres (1,800 ft).

Data are available from only three wells completed in the Santa Clara formation. The wells, in the general area of Anderson Reservoir, range in depth from 12 to 114 metres (40 to 375 ft). At the time of drilling, the reported depth to water was about 5 metres (16 ft); on test, the wells yielded from 45 to 375 litres per minute (12 to 100 gpm). Water quality data are not available for any of these wells; it may be assumed that the water produced is of acceptable quality as the wells are used for domestic purposes. The lower portions of many deep wells in the study area undoubtedly tap sediments of the Santa Clara Formation. A number of these wells produce excellent quality ground water used for irrigation and municipal purposes.

Volcanic Rocks

Volcanic rocks of late-Pliocene age crop out at a number of locations to the east of South Santa Clara Valley. Similar rocks also occur in the subsurface in certain parts of the valley as indicated by well logs. The volcanic rocks consist principally of basalt, although local areas of basic intrusive rocks also occur. Dibblee (1973) indicates that the age of some of the volcanic rocks is 3.5 million years, placing them in the latter part of the Pliocene Epoch. Post-Pliocene deformation has folded these sequences into a series of gentle anticlines and synclines, all having a northwest trend. The volcanic rocks are in fault contact with older rocks of the Great Valley Sequence and Franciscan Formation, as well as with younger materials. In places, the volcanic rocks are interbedded with sediments of the Santa Clara Formation. The thickness of the volcanic rocks has not been determined.

No wells are known to have been completed in the volcanic rocks. Carefully located wells may yield adequate water for domestic purposes; however, the incidence of dry holes will be significant. Ground water contained in the volcanic rocks is probably of acceptable quality for most beneficial purposes.

Valley Fill Materials

Valley fill materials, of Holocene age, occur in the gently sloping to level valley floor portion of South Santa Clara Valley, Hollister Basin, and tributary valleys. The materials range in thickness from less than a metre (3 ft) to probably as much as 30 to 50 metres (100 to 165 ft) near the axes of the valleys. Some of the valley fill materials are underlain by the Santa Clara and the Purisima Formations; identification of the contact between the valley fill materials and these other formations is not possible due to the marked similarity reported on well drillers' logs. Other parts of the valley fill materials are underlain by volcanic or pre-Pliocene rocks.

The valley fill materials are divided into two general groups: alluvium, which has a slope of less than 2 percent (i.e., a rise of 2 metres in 100 metres or 2 ft in 100 ft) and alluvial fan deposits, which have slopes greater than 2 percent. The alluvium has been further subdivided into older alluvium, younger alluvium, basin deposits, and stream channel deposits based on a combination of their physiographic expression and their soil characteristics.

The valley fill materials are the principal water produces in South Santa Clara Valley and Hollister Basin. Well yields vary widely depending on well construction and location. Yields from properly constructed wells are adequate to meet the needs of any beneficial use to which ground water is put. Quality and depth to water vary from point to point.

Alluvial Fans. Alluvial fan deposits occur around the margin of South Santa Clara Valley, Hollister Basin, and near the mouths of tributary valleys. The fans are composed of a heterogeneous, unconsolidated to semiconsolidated mixture of clay, silt, and sand; gravel lenses and stringers are common. The alluvial fans range in thickness from less than a metre (3 ft) to as much as 37 m (125 ft). Alluvial fan deposits rest on a variety of older materials, ranging from sediments of the Santa Clara Formation to rocks of the Franciscan Formation. In the valley, the fans are overlain by younger alluvial materials. Many of the zones of clay and gravel underlying the valley near Cochran Road belong to alluvial fan deposits which have become buried by younger alluvial materials.

Because of their heterogeneity, the alluvial fans contain ground water that is usually under some degree of confinement. Water quality generally is not a problem, and the alluvial fan deposits

whether exposed or under a veneer of alluvium, usually yield large amounts of ground water to properly constructed wells.

Older Alluvium. Deposits of older alluvium occupy the central portion of South Santa Clara Valley, from near Coyote south to Gilroy. Older alluvium consists of unconsolidated clay, silt, and sand which was formed as floodplain deposits. The older alluvium is characterized by a dense clayey subsoil which inhibits the downward movement of water; hence it possesses a very low recharge potential. Older alluvium is as much as 37 m (125 ft) thick near the axis of South Santa Clara Valley; it is underlain by alluvial fan deposits and a variety of older sediments, most notably those of the Santa Clara Formation and lacustral deposits from Lake San Juan. The older alluvium is overlain in a few places by younger alluvium and basin deposits.

Ground water in the older alluvium ranges from unconfined to locally confined. It provides adequate yields of water to wells up to 30 m (100 ft) deep; deeper wells located on the older alluvium draw from underlying materials. Most water produced by the older alluvium is of acceptable quality.

Younger Alluvium. Younger alluvium occurs in flat, well drained areas near Coyote and also from Gilroy south to the Hollister Basin. The younger alluvium is composed of unconsolidated deposits of silt, sand, and clay; zones of buried sandy gravel locally occur. In a manner similar to the older alluvium, younger alluvium has been formed as a floodplain deposit. In contrast to the older alluvium, however, the younger alluvium does not possess a well defined clay subsoil and thus water can percolate downward. The younger alluvium attains a maximum thickness of about 30 m (100 ft) and is generally underlain by alluvial fan deposits and older alluvium.

Ground water in the younger alluvium is generally unconfined. It provides adequate water for domestic purposes to wells generally less than 30 m (100 ft) in depth; deeper wells located on this unit tap underlying materials. Ground water in the younger alluvium is generally of acceptable quality.

Basin Deposits. Basin deposits occur in low-lying, undrained areas near Coyote and Gilroy in South Santa Clara Valley and in the Bolsa area of the Hollister Basin. The deposits consist of unconsolidated silty clay and sandy clay interbedded with zones of plastic clay and organic clay. All of these materials are very fine-grained and thus they have very low infiltration rates. As a result, ponding is prevalent during the wet season and saline soils are present in a number of areas. The basin deposits are as much as 30 m (100 ft) thick; they are underlain by alluvial materials as well as bottom sediments deposited by Lake San Juan.

The basin deposits are not a reliable source of good quality ground water. Because of their fineness of grain, they will yield only minimal amounts of water to wells; the water yielded may be

of poor quality. Wells situated on the basin deposits draw from underlying more permeable materials. Also because of the fineness of grain, the basin deposits act as a confining zone to underlying ground water and also inhibit any ground water recharge. The very low infiltration rate precludes any significant recharge from the Pajaro River in its course across the basin deposits.

Stream Deposits. Deposits of unconsolidated sand, gravel, and cobbles, containing little or no silt and clay, occur in and adjacent to the various stream channels. Related deposits, slightly elevated above the channel areas, also occur as stream terraces. Those deposits in the active channel areas are subject to movement during periods of high streamflows; during low flows, they are all nearly fully exposed. The stream deposits have a high infiltration rate, and are of great value as areas for natural and deliberate recharge. Because of their mobile nature during certain periods of the year, the stream deposits are not reliable sites for wells. Such wells, if constructed to preclude sanding, may be capable of providing fairly high yields from relatively shallow depths. Much of the ground water produced would be underflow from the adjacent stream.

The stream deposits are as much as 15 m (50 ft) thick; they are underlain by a variety of alluvial materials as well as older sediments and rocks. All ground water is unconfined and is of good to excellent quality.

Landslides

Landslides of Holocene age occur in a number of areas to the east of South Santa Clara Valley. The slides are located on exposures of the Santa Clara Formation as well as on volcanic rocks; faults are associated with many of the slides. Most of the landslides are up to 15 m (50 ft) thick and consist of a heterogeneous mixture of clay and silt; slides evolved from volcanic rocks contain a substantial quantity of broken rock. Because of their relative instability, water wells have not been drilled into slide materials. Many of the slides are saturated as shown by the springs and seeps found at their lower extremities.

Base of Water-Bearing Materials

Rogers and Williams (1974) presented a map showing the thickness of the alluvial materials in South Santa Clara Valley based on the analysis of well logs (31 logs in current study area) that bottomed in "bedrock". A modified map, shown on Figures 5A and 5B, presents elevation contours on the base of the alluvial materials derived from the analysis of logs from 89 wells intercepting bedrock (shown on well logs as "rock", "hill formation", etc.). Figure 5 differs from the map presented by Rogers and Williams in that a buried hill and several buried promontories have been identified.

LEGEND

Ground elevation contours outside of valley floor area; contour interval 200 ft. (60 m)

Subsurface elevation contours on base of alluvial materials; contour interval 100 ft. (30 m)

Boundary of valley floor area

Well extending below base of alluvial materials (intercepts "bedrock")

Fault, dotted where concealed

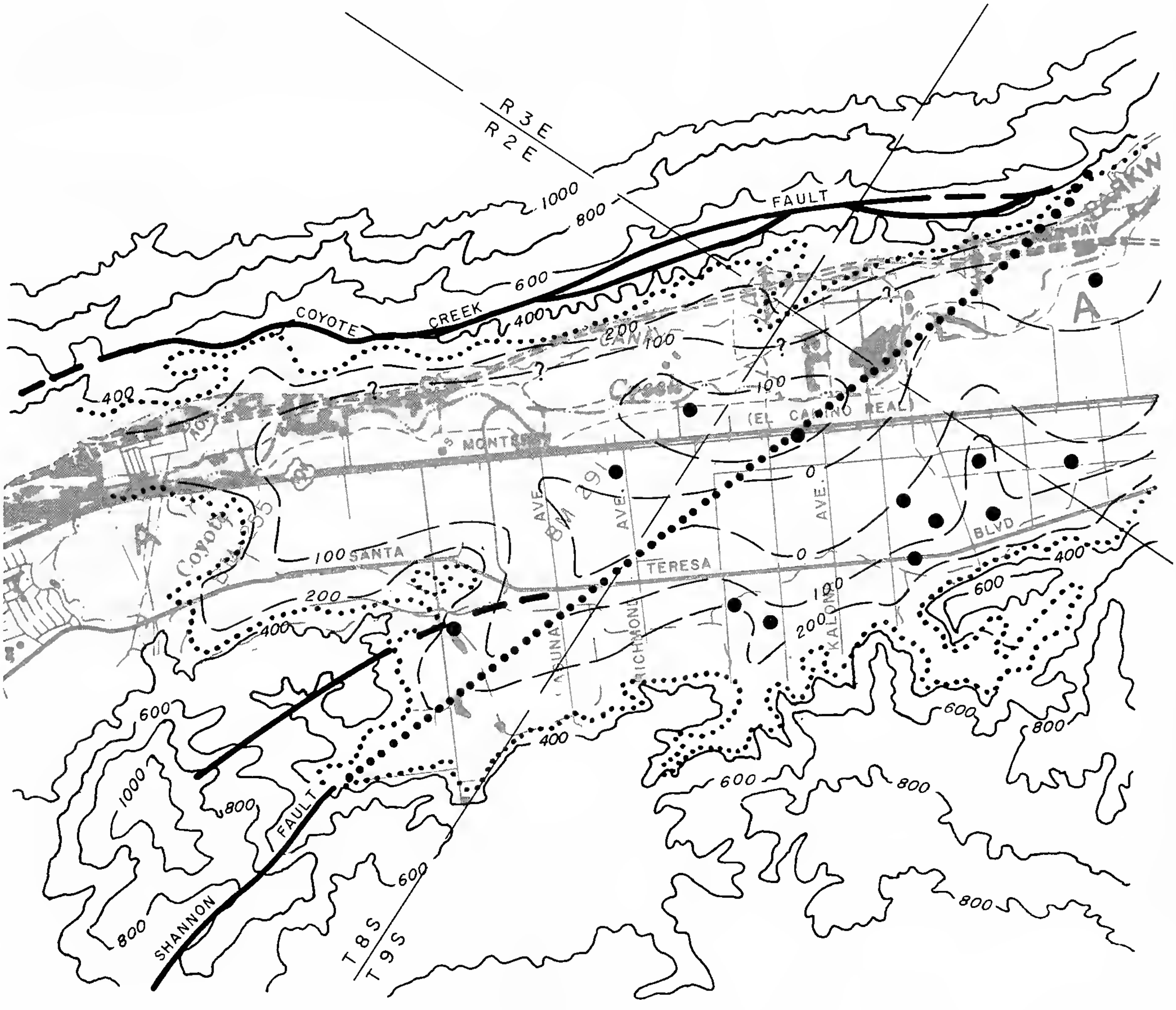
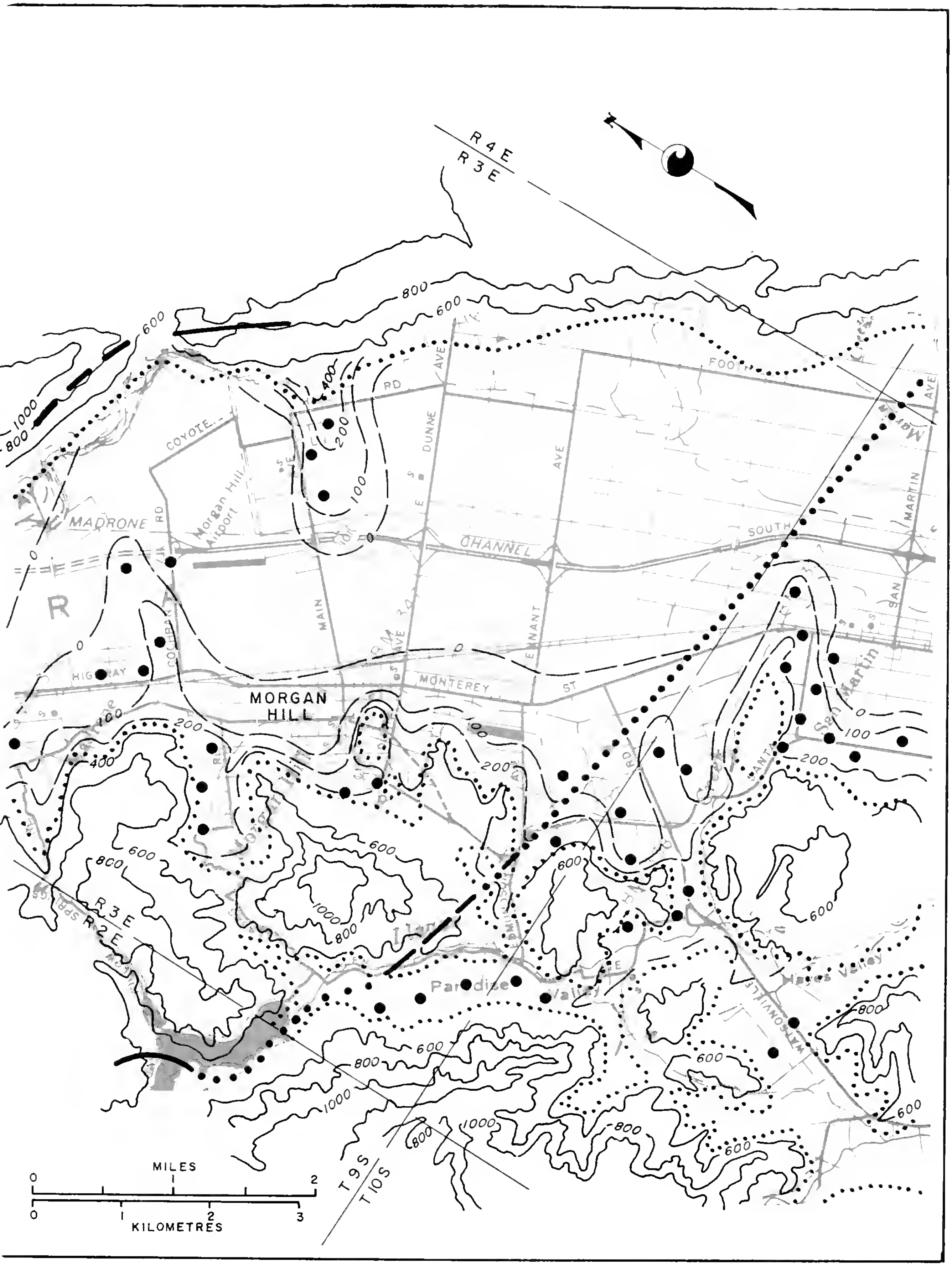


FIGURE 5A.--Elevation Contours on Base of



Alluvial Materials, South Santa Clara Valley.

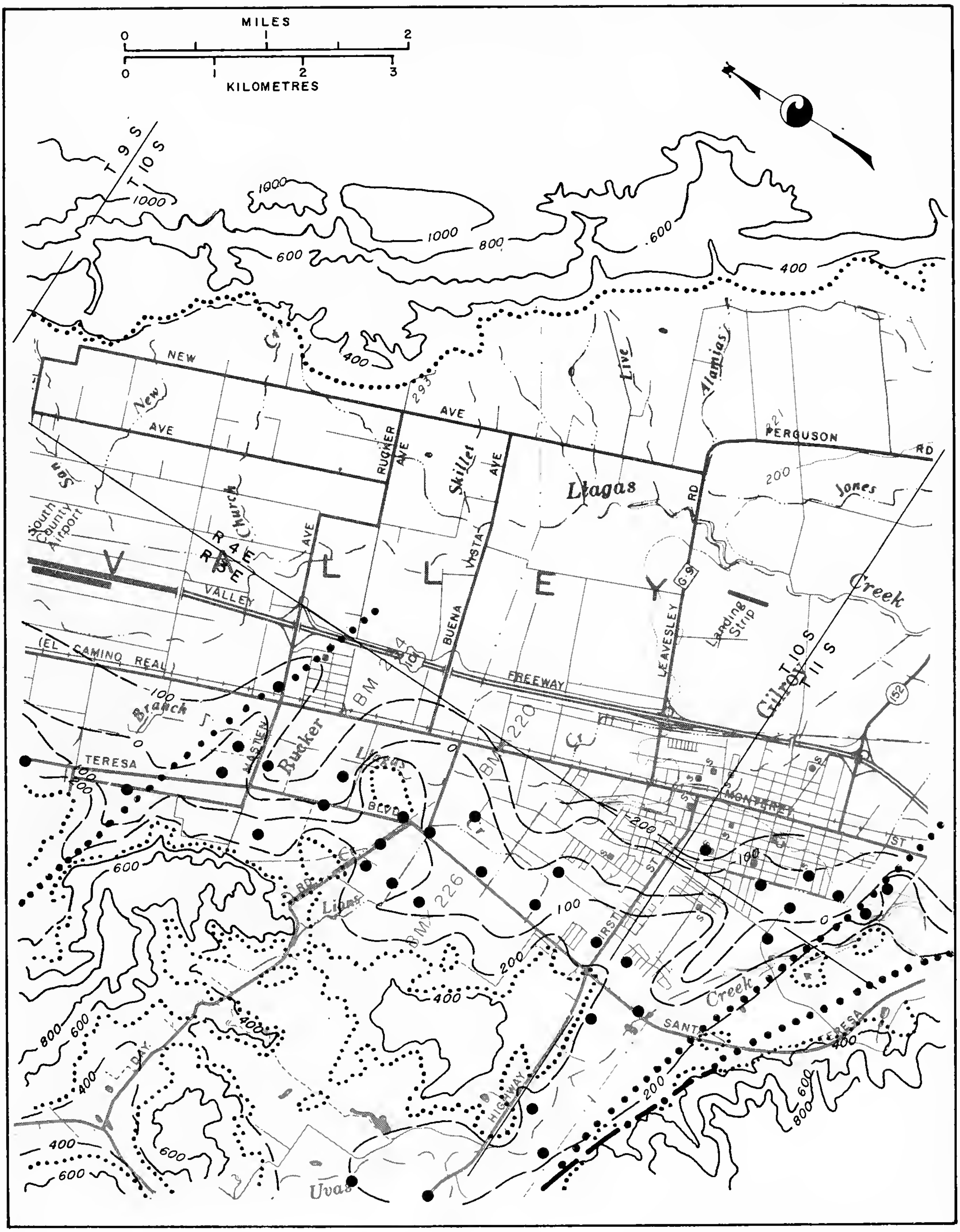


FIGURE 5B.--Elevation Contours on Base of Alluvial Materials, South Santa Clara Valley.

A buried hill, shown on Figure 5A, exists under Highway 101, roughly between Richmond and Kalana Avenues, a distance of about 2 kilometres (1.2 mi). The hill is bounded on the south by the Shannon fault. Sediments overlying the hill are on the order of 60 m (200 ft) thick, while they attain a thickness of from 90 to 120 m (295 to 395 ft) in adjacent areas. The ancestral drainage apparently originated near what is now Coyote Narrows, flowed southerly around the hill and joined the ancestral south-flowing Coyote Creek near the intersection of Cochran Road and Madrone Channel. Subsequent deposition, principally by Coyote Creek, buried the hill. The drainage ultimately was reversed after Coyote Narrows had been formed, possibly by headward erosion and stream capture by an ancestral tributary to Guadalupe River in North Santa Clara Valley.

Four buried bedrock promontories also are shown on Figure 5A. One is near the intersection of Cochran Road and Monterey Highway; it extends easterly from the hill front about 2 km (1.2 mi). About 75 m (245 ft) of alluvial materials overlie it; alluvial materials are over 100 m (330 ft) thick on each side. The south side of the promontory appears to be quite steep. Channel deposits of the ancestral Coyote Creek occur adjacent to a portion of this buried escarpment.

A second buried promontory occurs between Main and East Dunne Avenues, east of the Highway 101 Freeway. Here, sediments are on the order of 80 to 90 m (260 to 295 ft) deep overlying bedrock. Rock has not been intercepted by any wells on either side of the promontory, but it lies under a sedimentary cover of at least 120 m (395 ft). This promontory apparently forced the ancestral Coyote Creek to flow along the west side of the valley in its southward course toward the Pajaro River.

Two buried promontories, in part controlled by the Chesbro fault, occur near Llagas Creek. The crest of the lesser occurs south of the intersection of Monterey Street and Watsonville Road; here sediments are less than 40 m (130 ft) deep over the buried hill. The larger promontory is an extension of the east-trending hill that forms the south bank of Llagas Creek near San Martin. This latter promontory extends as far east as Highway 101 (South Valley Freeway), a distance of 1.5 km (1 mi); the depth of sediments overlying it is about 60 m (200 ft). Llagas Creek apparently flowed between these two promontories, as there are layers of buried stream channel materials along the present course of the creek to a depth of 75 m (245 ft).

The alluvial materials making up South Santa Clara Valley rest on a now-buried bedrock trough. The axial line of this trough begins near Coyote at an elevation of about 30 m (100 ft); here, valley-fill materials are at most about 50 m (165 ft) thick. The axial line passes below sea level near Laguna Avenue, where the sediments are about 80 m (260 ft) thick. It then meanders south-easterly at an ever-decreasing elevation, but its depth and location cannot presently be determined because of a lack of deep

well data. Near Gilroy, the axial line is below elevation -150 m (-490 ft), based on a 213 m (700 ft) deep well in that city that did not penetrate bedrock. In the Bolsa area of San Benito County, a well bottomed in sedimentary material at an elevation of -290 m (-950 ft). Although no bedrock was encountered, it is probable that the lower portion of the well penetrated the Purisima Formation. Kilburn (1972) indicates that in the Bolsa area, the top of the lowermost member of the Purisima Formation (saline water-bearing) is at an elevation of about -500 m (-1,640 ft) and the elevation of the top of bedrock is about -900 m (-2,950 ft). These data place the top of the lowermost member of the Purisima Formation at a depth of about 550 to 600 m (1,800 to 1,970 ft). According to Kilburn, the base of fresh water is at some indeterminate depth above the top of the lowermost member of the Purisima Formation.

Faults

South Santa Clara Valley is an elongate feature situated roughly parallel and adjacent to a number of major fault zones. To the east, about 7 km (4 mi), is the Madrone Springs fault, an easterly branch of the Calaveras fault. The trace of the Calaveras fault ranges from 1 to 5 km (0.5 to 3 mi) east of South Santa Clara Valley; it crosses the floor of the Hollister Basin. Some 15 km (9 mi) west of South Santa Clara Valley is the San Andreas fault, which traverses the Santa Cruz Mountains. Associated with these faults are the nearly parallel Ben Trovato, Berrocal, Silver Creek, and Sargent faults. Compound movement along all of these faults has created a series of en echelon subsidiary faults, all exhibiting left-lateral displacement, which crosses diagonally beneath the floor of South Santa Clara Valley.

Of all of these major faults, only the Calaveras fault has any significant effect on ground water movement in the study area. All of the others traverse upland areas outside of the limits of the South Santa Clara Valley-Hollister Basin. South from San Felipe Lake, the Calaveras fault extends across Hollister Basin. Here, the fault is indicated by a number of sag ponds strung out along Tequisquita Slough (see Figure 3C). According to Kilburn, the fault forms a barrier to any westward movement of ground water. Because of this, the Calaveras fault was picked as the eastern boundary of the study area.

The Shannon fault has been shown by Bailey and Everhart (1964) as entering South Santa Clara Valley near the west end of Bailey Avenue. Well log data suggest that the fault crosses the valley and apparently joins the Coyote Creek fault near the east end of Burnett Avenue. The Shannon fault appears to have left-lateral displacement and may have caused the 2-km (1.2 mi) offset in the axis of the valley. Surficial materials to a depth of about 20 m (65 ft) do not appear to have been affected by movement along the fault. However, some buried stream channel materials below that depth appear to have been offset an undetermined distance. The

fault does not appear to be a significant barrier to ground water movement because of the great degree of interconnection between the various buried stream channel deposits.

Dibblee (1973) mapped an unnamed fault passing under Chesbro Reservoir and a part of Paradise Valley, and possibly extending as far as Edmundson Avenue. Rogers and Williams (1973) identified this as the Chesbro fault. The Chesbro fault apparently continues eastward across South Santa Clara Valley at least as far as the intersection of Foothill and San Martin Avenues. It may continue eastward from that location, passing through exposures of the Santa Clara Formation and joining the Coyote Creek fault near the point where the latter makes an abrupt turn to the east. Like the Shannon fault, the Chesbro fault appears to be of left-lateral displacement and may be responsible for the change in direction of the axis of the valley as well as for the bedrock ridge along the right bank of Llagas Creek upstream from San Martin. Near the east and west sides of the valley, some of the water-bearing materials appear to have been offset, causing a restriction in ground water movement across the trace of the fault.

A southeast-trending fault, mapped by Dibblee, passes to the north of Uvas Reservoir, crosses Hayes Valley, and ends near Santa Teresa Boulevard, about 5 km (3 mi) north of Gilroy. Rogers and Williams identified this fault as a branch of the Ben Trovato fault zone. Analysis of well logs suggests that this fault extends across South Santa Clara Valley and intersects an unnamed fault near the east end of Leavesley Road. The latter fault has a trace roughly parallel to the Calaveras fault and is approximately 750 m (2,460 ft) west thereof. The fault that crosses the valley apparently has left-lateral displacement as suggested by the subsurface bedrock contours shown on Figure 5B. Well log data indicate that materials less than 50 m (165 ft) in depth have not been greatly affected by movement along the fault. Buried stream-channel materials east of Highway 101 are unaffected by the fault zone, as ground water appears to move down gradient unimpeded. In contrast, to the west of Highway 101, water-bearing materials may have been offset, as there is a restriction to ground water movement across the trace of the fault.

Allen (1964) identified the Carnadero fault as having a southeasterly orientation and running along the base of the mountains to the southwest of Gilroy. Well logs suggest that this fault branches near Santa Teresa Boulevard. One branch apparently heads in the direction shown by Allen and joins the Calaveras fault south of Shore Road, in San Benito County. The trace of this fault in the Bolsa area is suggested from the lack of continuity between wells below depths of about 50 to 100 m (165 to 330 ft) and from noting that water level fluctuations on the east side and west side of the Bolsa area are markedly different.

A northerly branch of the Carnadero fault leaves the main trace near Santa Teresa Boulevard and apprently joins the Calaveras fault in the vicinity of San Felipe Lake. Like the main trace of

the fault, this subsidiary feature does not cut any water-bearing materials closer than about 50 to 100 m (165 to 330 ft) below ground surface. There appears to be a restriction of ground water movement in the area east of Frazier Lake Road.

Paleodrainage System

To fully understand the geohydrologic system in South Santa Clara Valley, it was necessary to define and delineate the interconnected network of buried stream channels. This was accomplished through the use of the computer-assisted program of analysis of water well drillers' logs, called the GEOLOG program. One element of this program uses lithologic data shown on water well drillers' logs and converts these data to a series of maps of discrete subsurface intervals showing zones of sandy-gravel materials (the buried stream channels) and zones of fine-grained materials (the interstream clayey areas). These subsurface maps, showing the now-buried meandering stream channel materials, are presented as Figures 6A through 6J. Wells that penetrated the entire thickness of the alluvial fill and bottomed in bedrock also provided data on the configuration of the underlying bedrock surface. A detailed discussion of the GEOLOG program and its application to the paleodrainage, ground water storage capacity, and transmissivity of a ground water basin is presented by Ford and Finlayson (1974) and also by Ford and others (1975).

The northern part of South Santa Clara Valley (that portion north of the drainage divide near Morgan Hill) contains a dual paleodrainage system. The lower system is below an elevation of about zero, and is tributary to an ancestral southward-flowing Coyote Creek. Above the zero elevation, northward-trending Coyote Creek deposits are found in ever-increasing amounts. The creek appears always to have entered South Santa Clara Valley near its present entry location. It was probably shifted to the north by a combination of construction of its own alluvial fan, deflection by an eastward-projecting promontory, and stream capture.

From the drainage divide south to the Pajaro River, there appear to be a number of buried Coyote Creek stream channels which meandered over the floor of the valley. Many tributary streams, the most prominent of which were the ancestral Llagas and Uvas Creeks, entered Coyote Creek so that by the time it reached the Pajaro River (which was at about its present location), Coyote Creek was a stream of some consequence. It appears that the ancestral Coyote Creek entered the Pajaro River near the mouth of the present Carnadero Creek.

Coyote Creek did not empty into the Pajaro River continuously; at times in the past it flowed directly into one of the lakes that occupied the lower portion of the valley. When this was the case, the deposits of stream channel materials terminate near the ancestral shoreline; beyond that point are deposits of lake-bottom sands and clays. Other streams tributary to Coyote Creek (Uvas

Creek, Llagas Creek, etc.) also directly entered the lakes; some of these streams also probably constructed deltas at the point of entry into still water.

Under the Bolsa area of San Benito County it is difficult to identify many buried stream channel deposits due to the lack of adequate well data. It appears that a number of streams flowed westerly from the area east of the Calaveras fault, but these stream channel deposits could not be traced west of the fault. A broad subsurface channel converges on the Pajaro River from the south in the elevation interval from 15 to 30 m (50 to 100 ft). The origin of the channel may be from Santa Ana Creek or from the San Benito River.

Lake Deposits

South Santa Clara Valley has been the site of at least two large lakes. According to Herd and Helley (1977), the earlier lake, Lake San Benito, had a maximum water elevation of about 90 m (295 ft); the lake persisted at this level for some time during the Holocene, at least 5,000 years ago. In the valley today, at elevations below 90 m (295 ft), there are ever-increasing thicknesses of lacustral clays and silts. Some of the more surficial clays underlying the portion of the valley below elevation 60 m (195 ft) can be attributed to deposition on the bed of a more recent, lower-stage lake, called Lake San Juan by Jenkins (1973).

The lake-bottom clays appear to be fairly continuous and form a series of confining beds. The Lake San Benito clays extend as far north as San Martin Avenue, where they are at a depth of about 50 m (165 ft). Underlying the lake-bottom materials are pre-lacustral sand and gravel deposits that may be correlative with the upper portion of the Santa Clara Formation. The lake-bottom clays slope southward and become progressively thicker until in the Bolsa area they are on the order of 80 m (265 ft) thick. Underlying these materials in this latter area are coarse-grained materials that may either belong to the uppermost portion of the Santa Clara formation or may be unnamed post-Santa Clara and pre-Lake San Benito sediments.

The present upper limit of the Lake San Benito clays probably does not represent the uppermost level of lake-bottom deposition. Post-lake erosion and deposition has formed a zone of interconnected aquifer material some 20 to 40 metres (65 to 130 ft) thick overlying the lake-bed deposits and extending from San Martin Avenue nearly to Bloomfield Road. Near Bloomfield Road, the coarse-grained materials grade laterally into progressively finer-grained materials. Occasional zones of granular material occur to the south and were probably formed as the result of lake-bottom deposition of sandy material.

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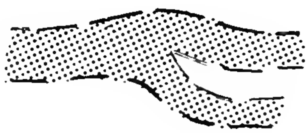
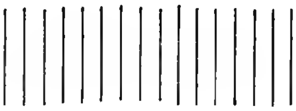
Overlying the zone of post-Lake San Benito sediments, in valley areas below elevation 60 m (195 ft), is a zone of lacustral clay attributable to Lake San Juan. These clays attain a maximum thickness of about 60 m (195 ft) under the Pajaro River where they appear to rest directly on the older Lake San Benito clays. Like the older clays, these clays also have discrete zones of sandy material.

Under the Bolsa area, where the Lake San Benito and Lake San Juan clays attain maximum thickness, the clays are present to a depth of about 140 m (460 ft), or to elevation -100 m (-330 ft). Partly because of the great thickness of clayey material that underlies an area extending from Bloomfield Road south to Shore Road (San Benito County) and from near Corporal east to the Calaveras fault, an area of about 64 km^2 (25 mi^2), there appears to be very little hydraulic continuity between the Morgan Hill-Gilroy area and the Hollister area, except possibly at depths not presently tapped by most wells.

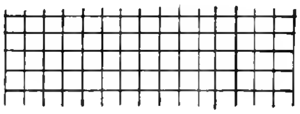
LEGEND



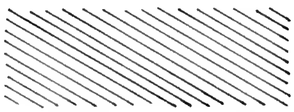
Subsurface deposits of coarse-grained materials representing now-buried stream channels. Other areas represent fine-grained interstream materials.



Subsurface extent of water-yielding materials outside of ground water basin for elevation interval shown (principally Santa Clara and Purisima Formations).



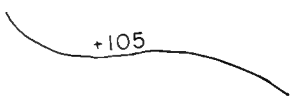
Subsurface extent of volcanic rocks for elevation interval shown.



Subsurface extent of nonwater-yielding rocks for elevation interval shown (principally Franciscan Formation, Great Valley Sequence, and Miocene marine rocks).

Trace of fault crossing ground water basin.

Trace of fault in rocks outside of ground water basin.



Ground surface elevation contour (in metres).

Present valley floor boundary.

FIGURE 6A.--Subsurface Deposition, Legend for Figures 6B Through 6J.

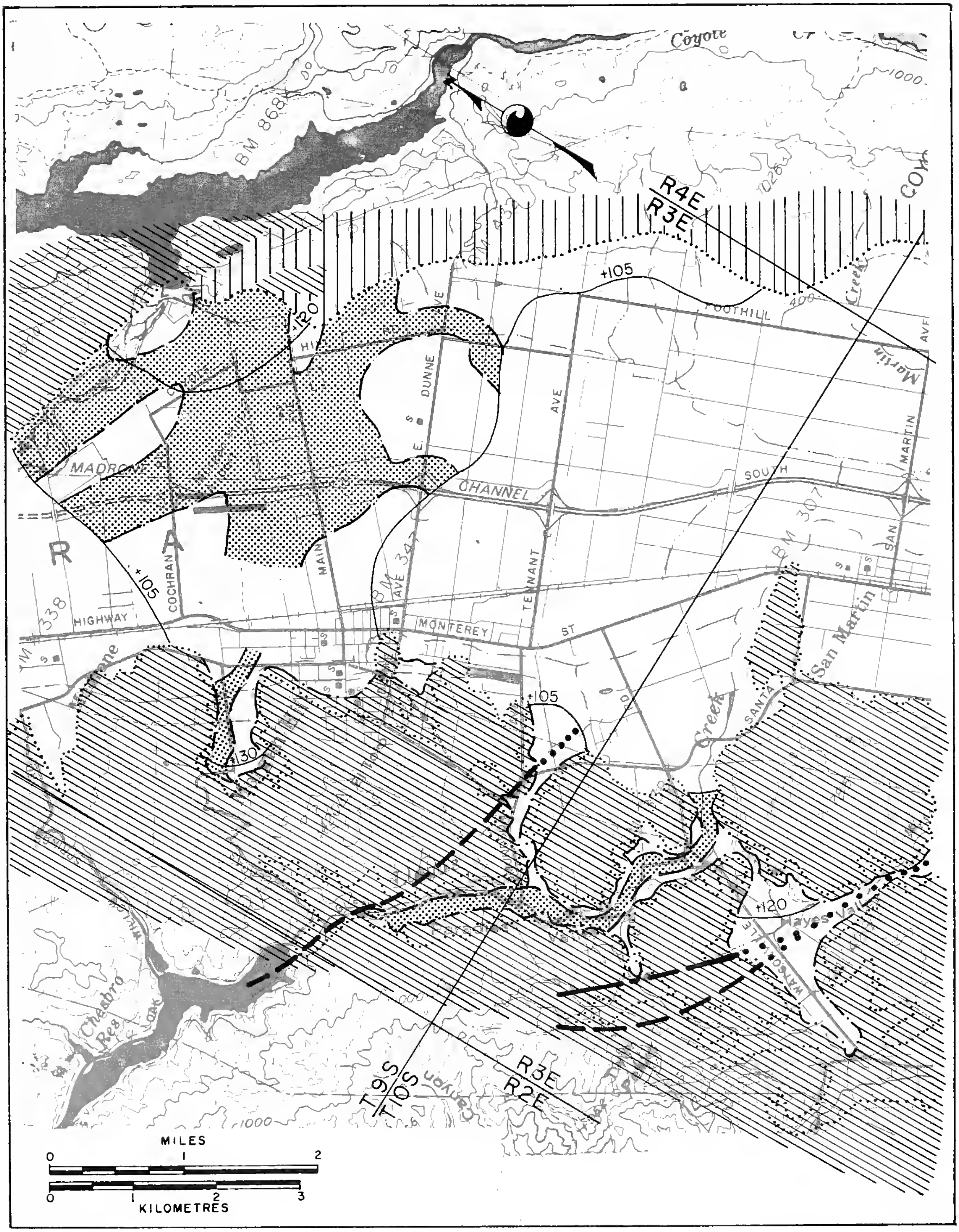


FIGURE 6B.--Subsurface Deposition, +105m to +120m, Coyote and Llagas Subbasins.

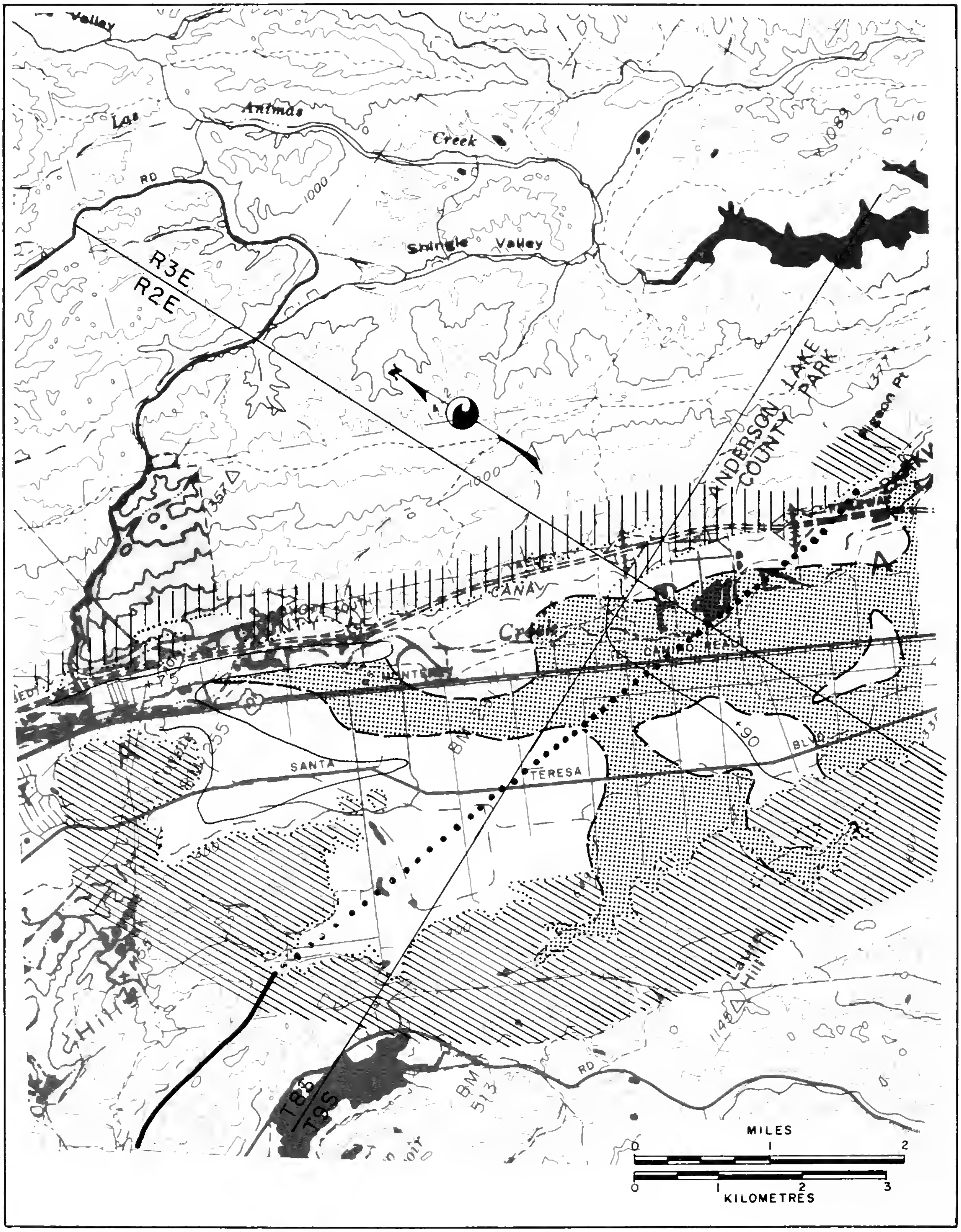


FIGURE 6C.--Subsurface Deposition, +75m to +90m,
Coyote Subbasin.

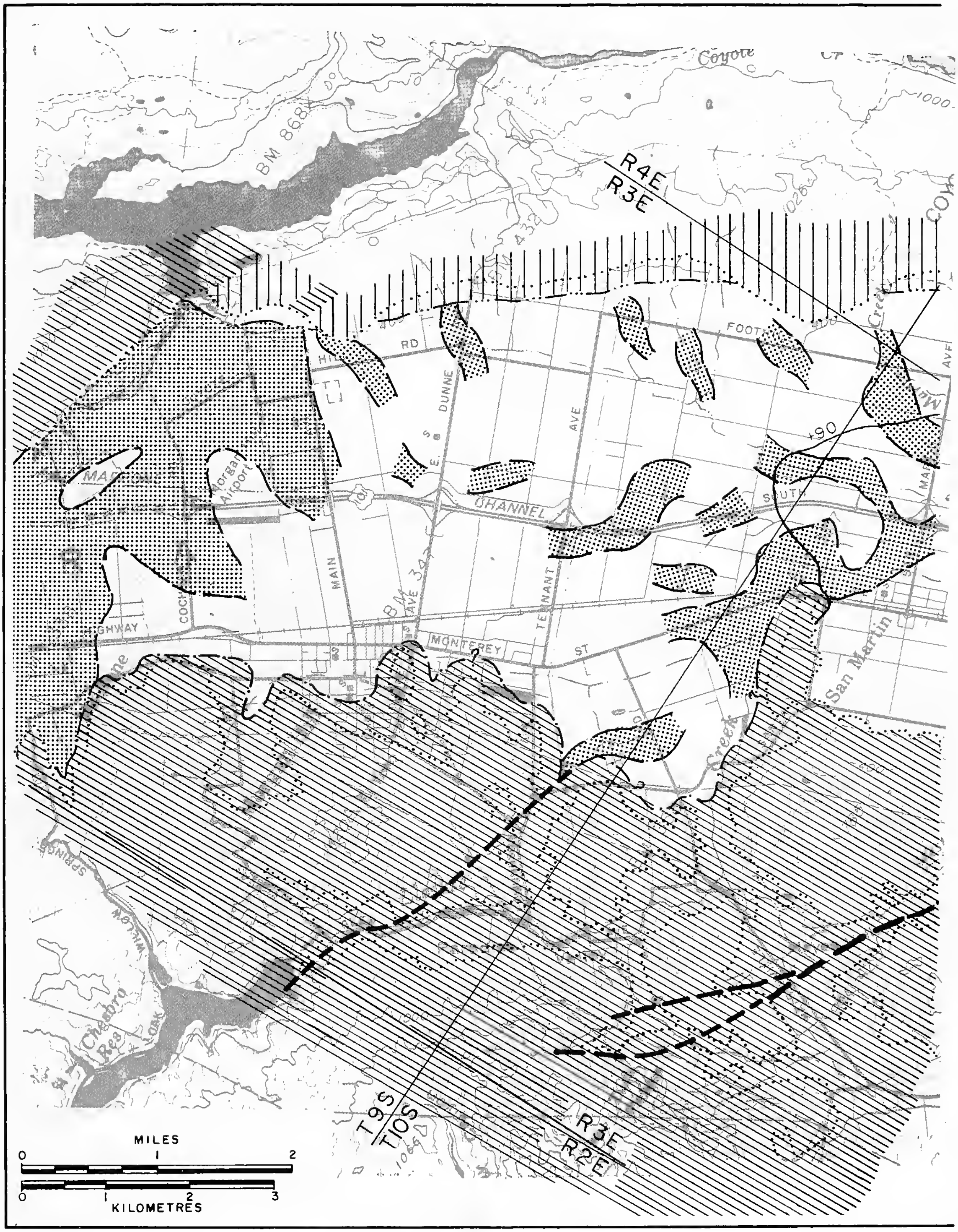
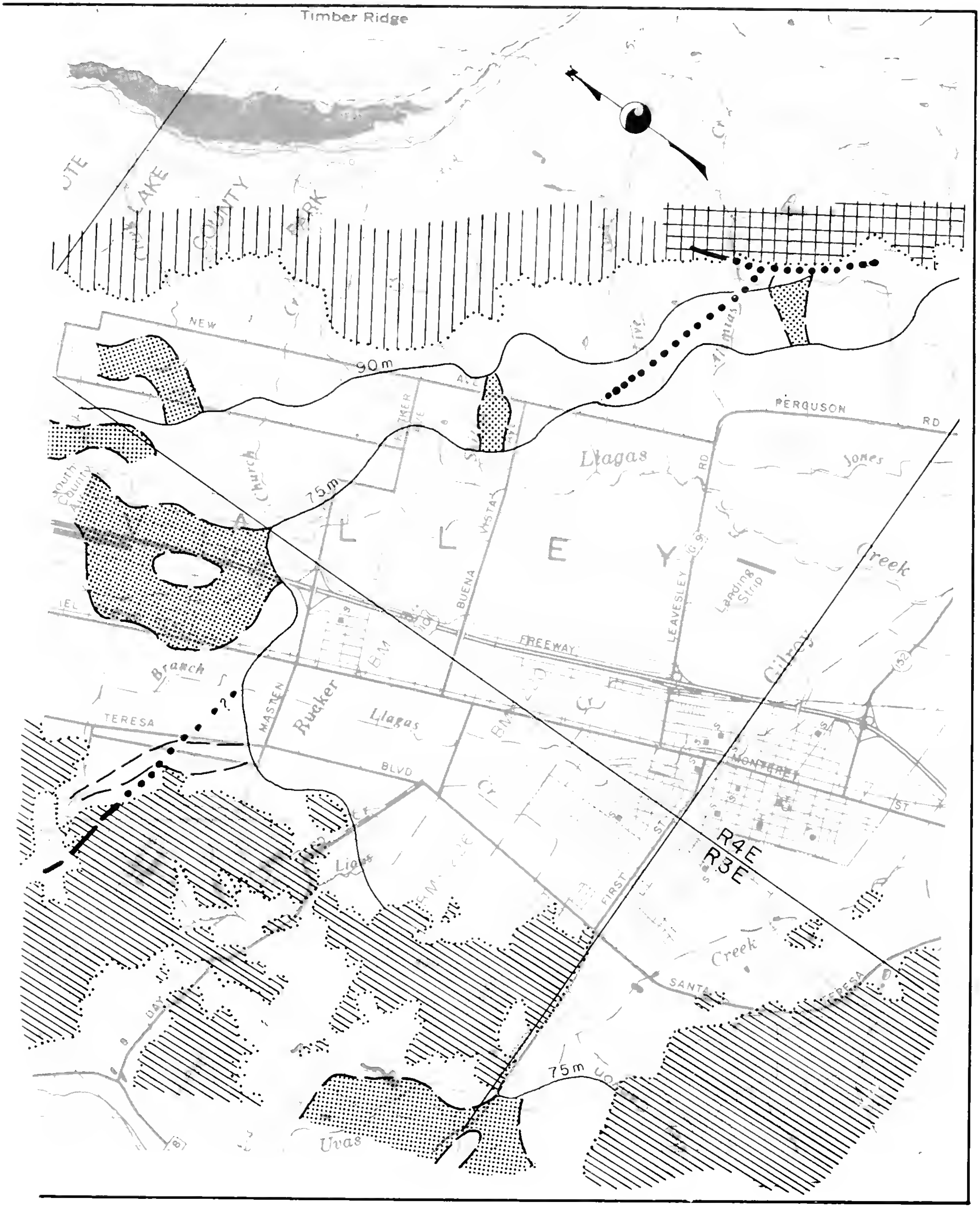


FIGURE 6D.--Subsurface Deposition, +75m to



90m, Coyote and Llagas Subbasins.

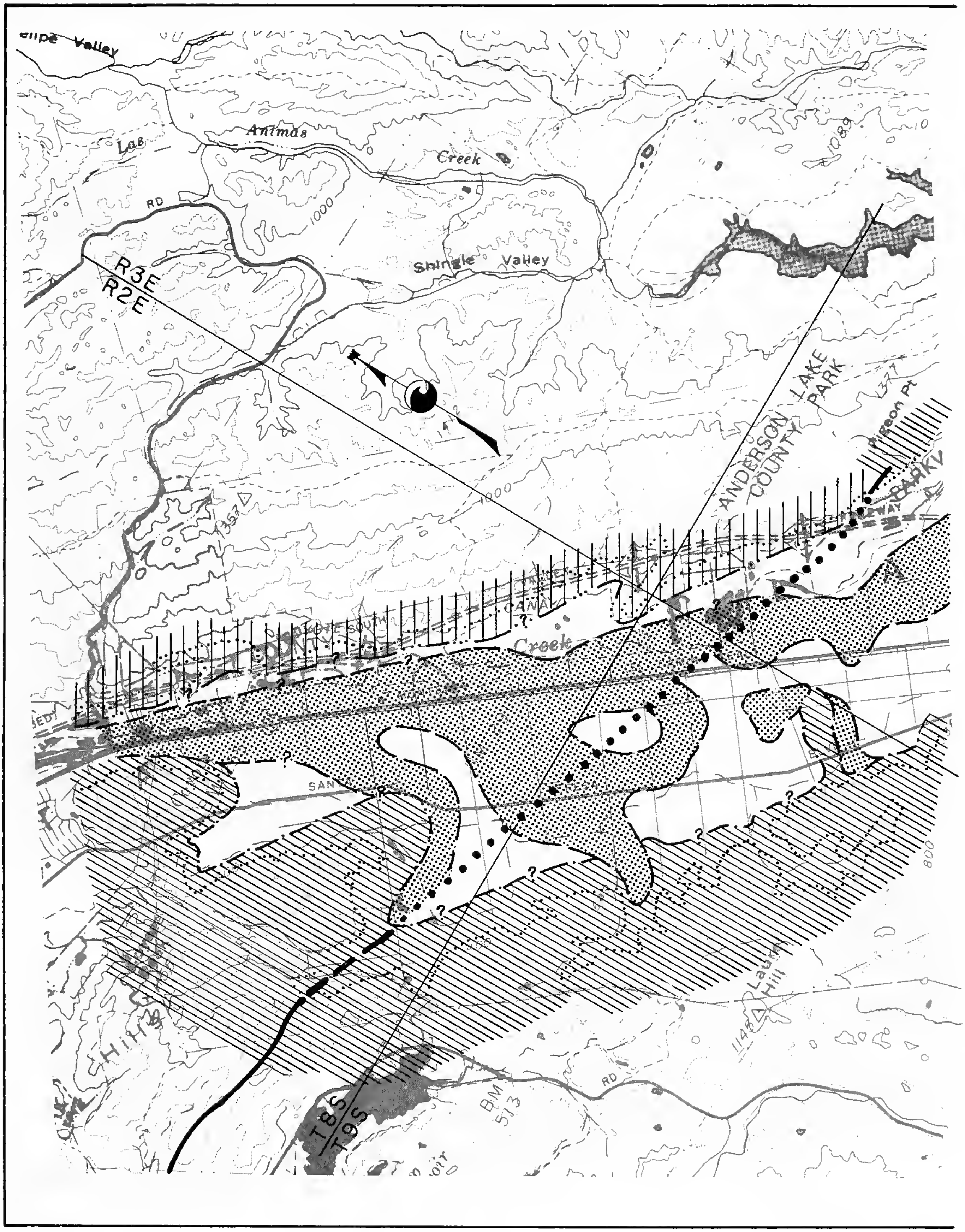


FIGURE 6E.--Subsurface Deposition, +45m to

+60m, Coyote and Llagas Subbasins.

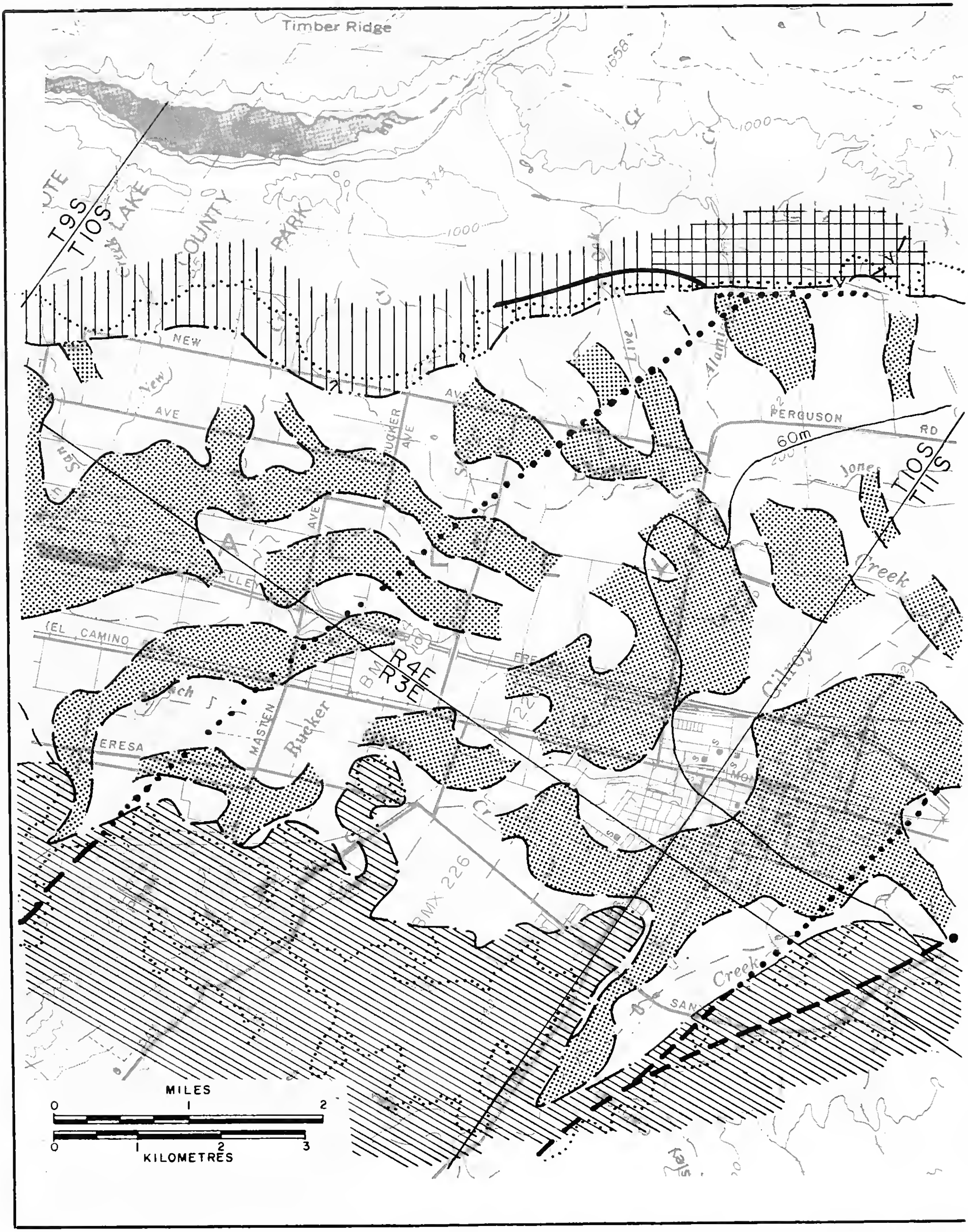
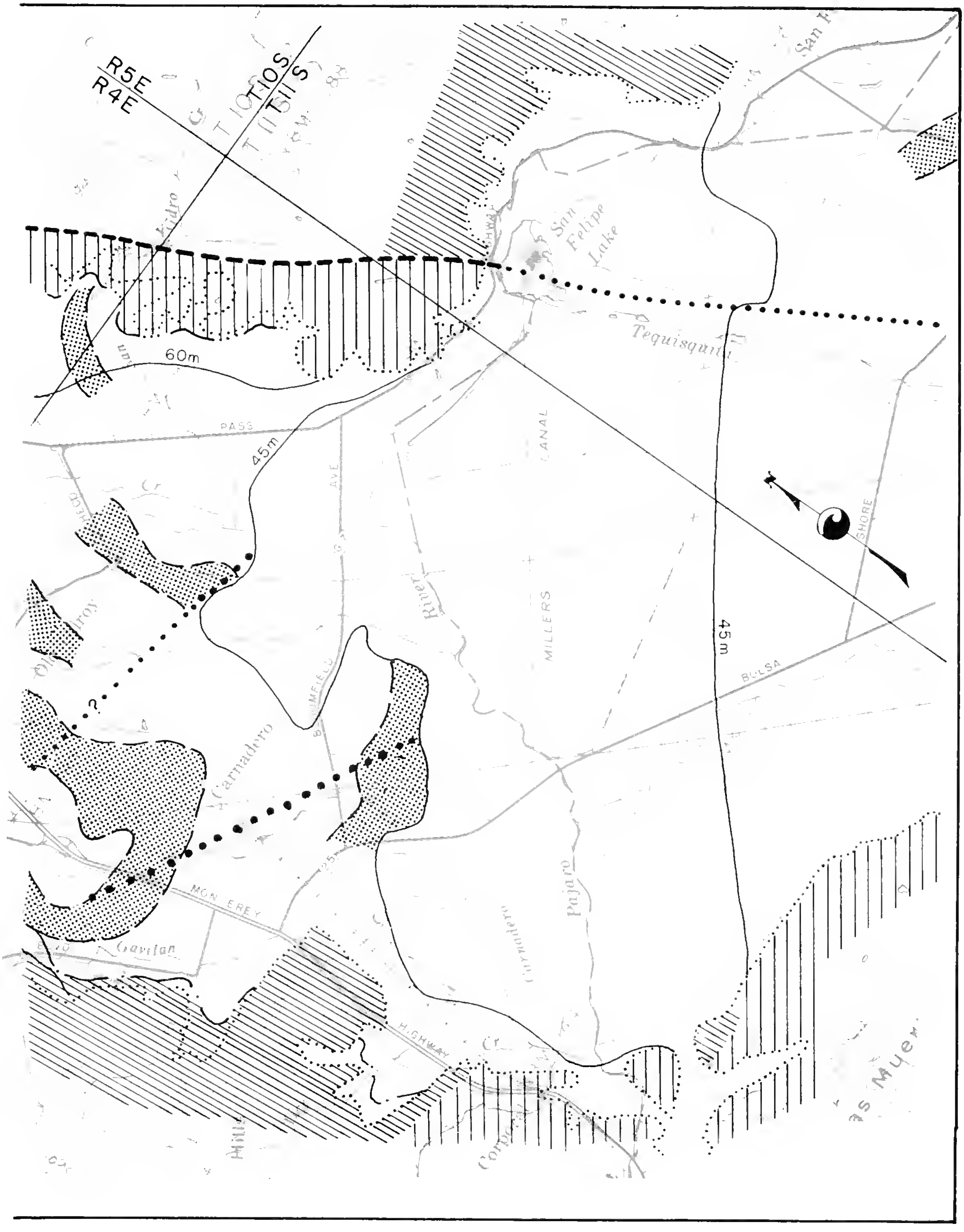


FIGURE 6F.--Subsurface Deposition,



+45m to +60m, Llagas Subbasin.

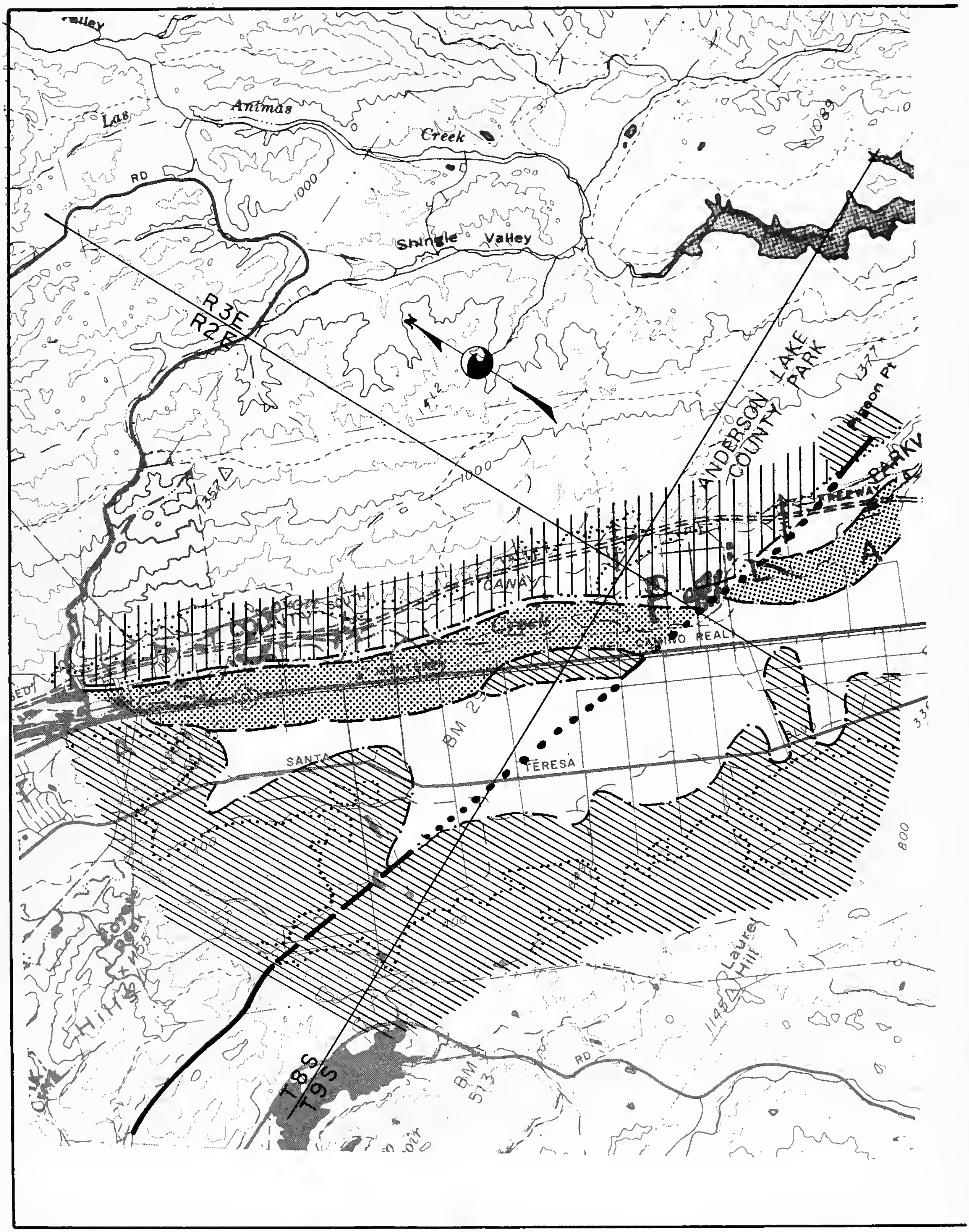
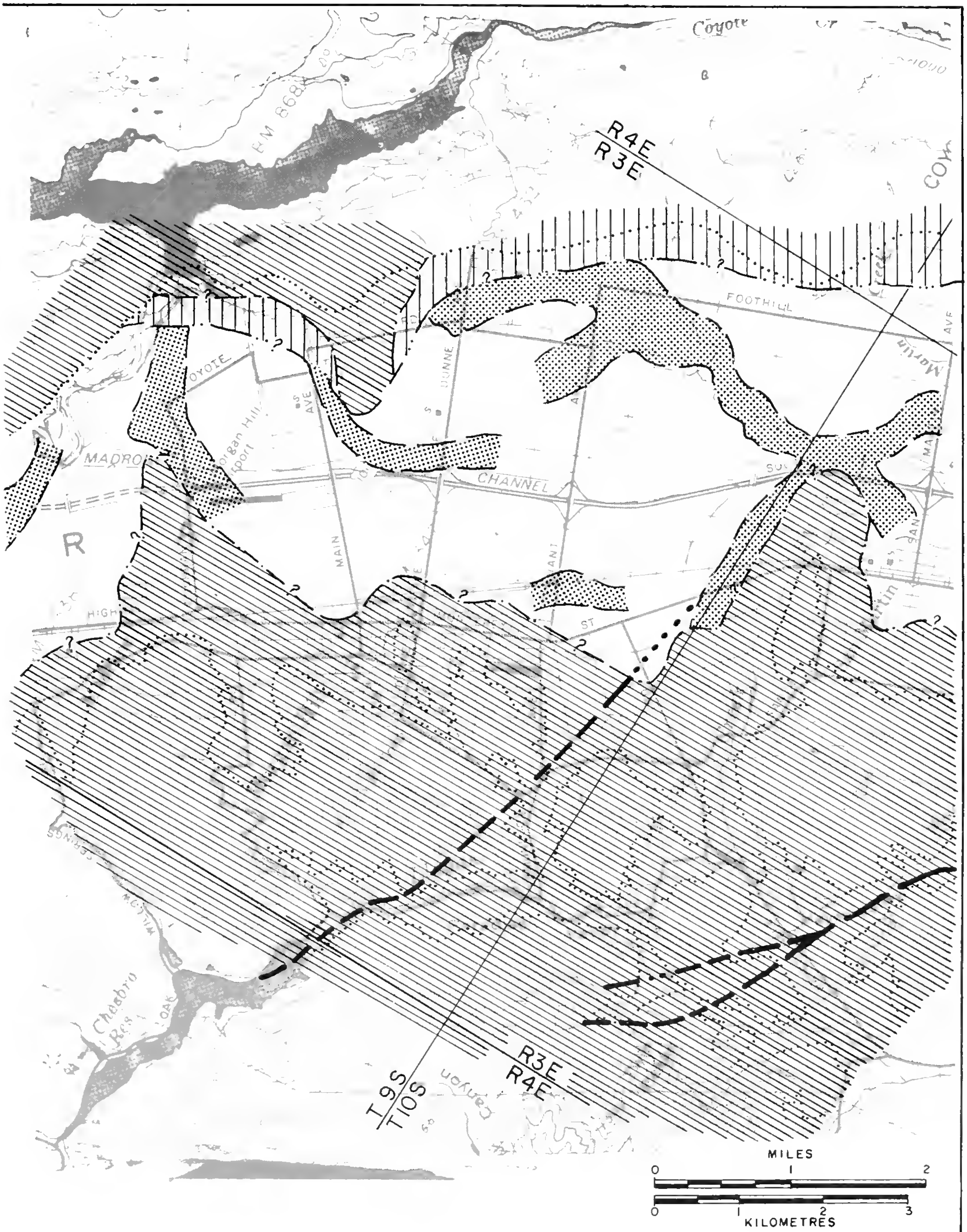


FIGURE 6G.--Subsurface Deposition, +15m to



+30m, Coyote and Llagas Subbasins.

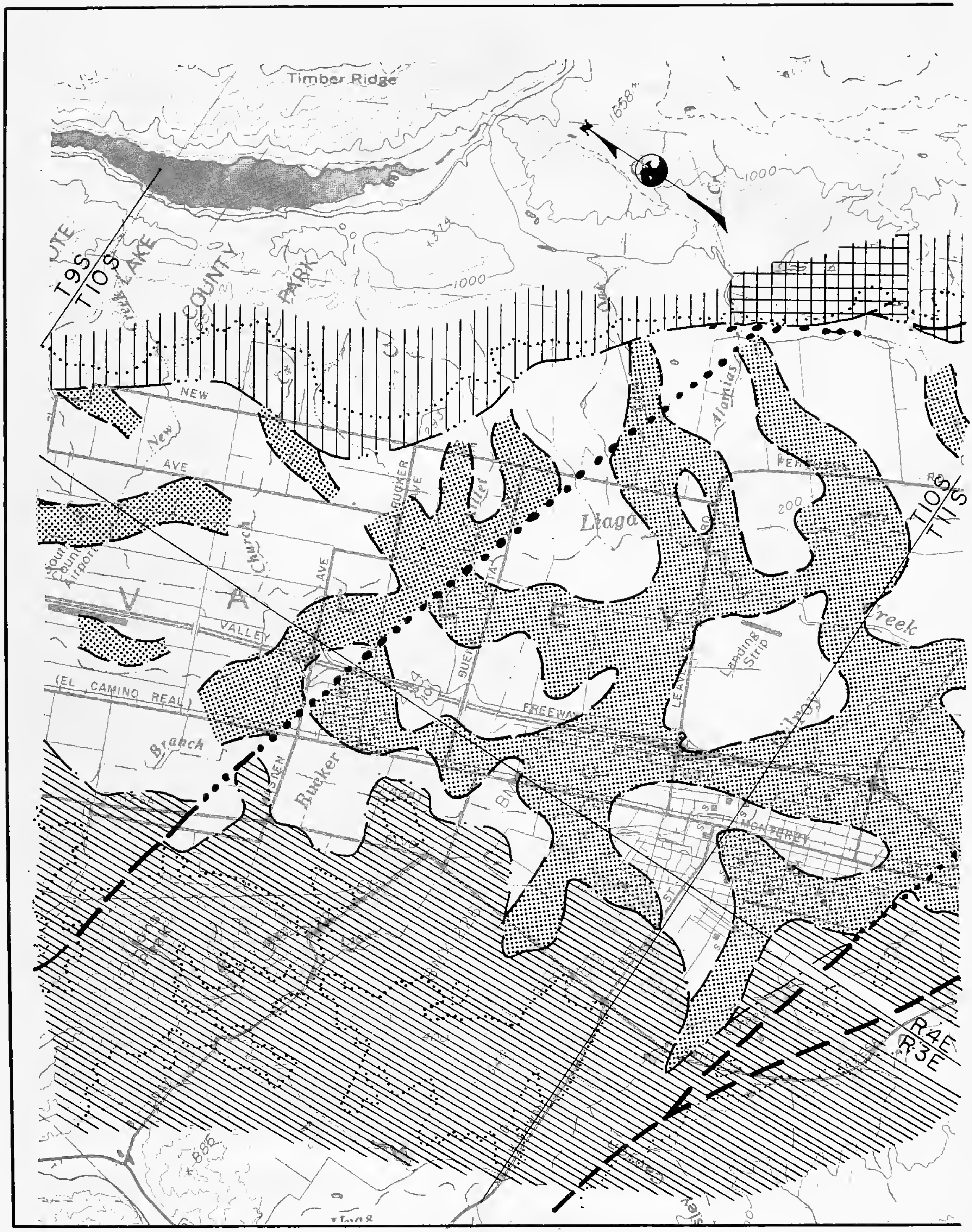
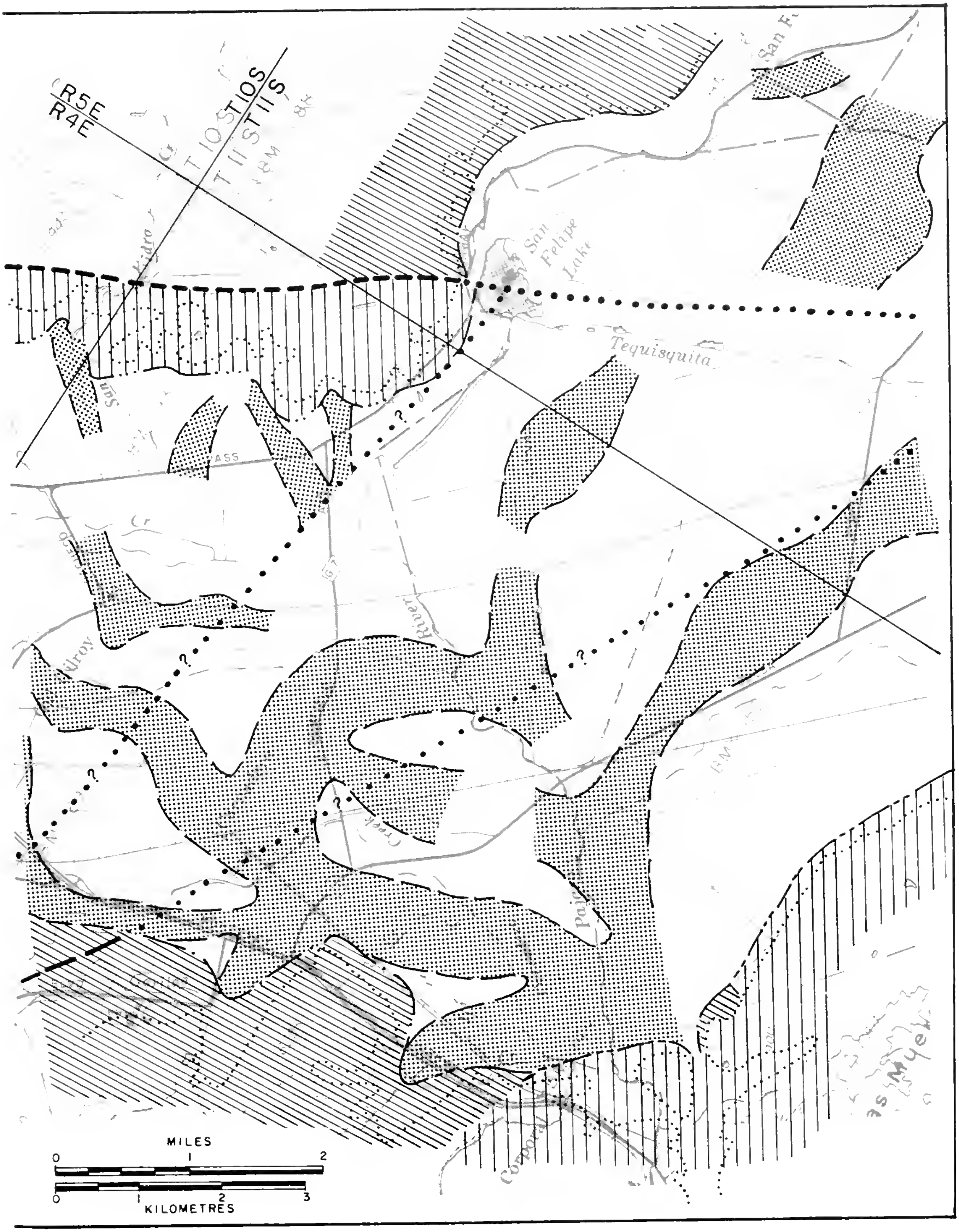


FIGURE 6H.--Subsurface Deposition, +15m to



+30m, Llagas and Bolsa Subbasins.

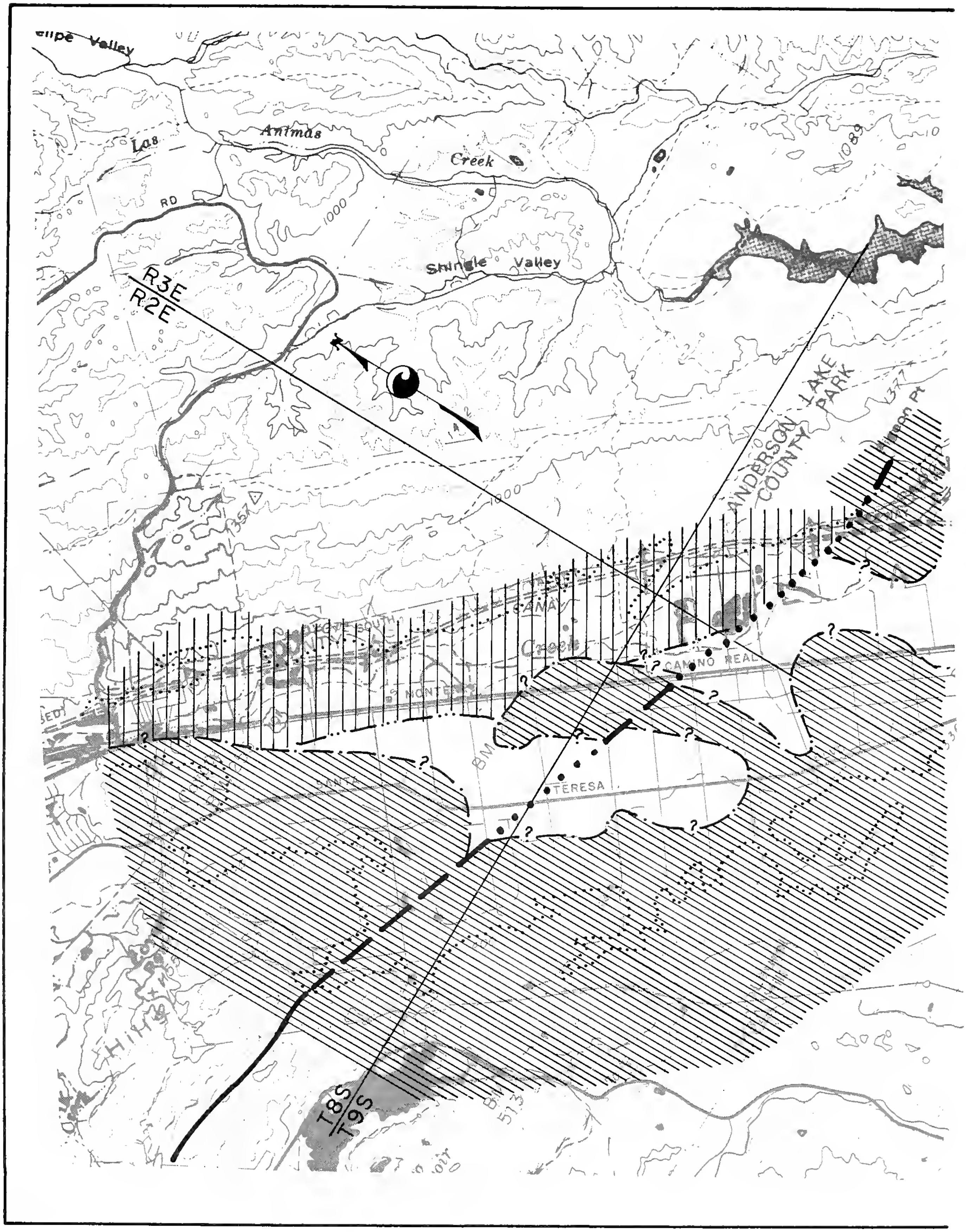


FIGURE 6I.--Subsurface Deposition, 0m to

-15m, Coyote and Llagas Subbasins.

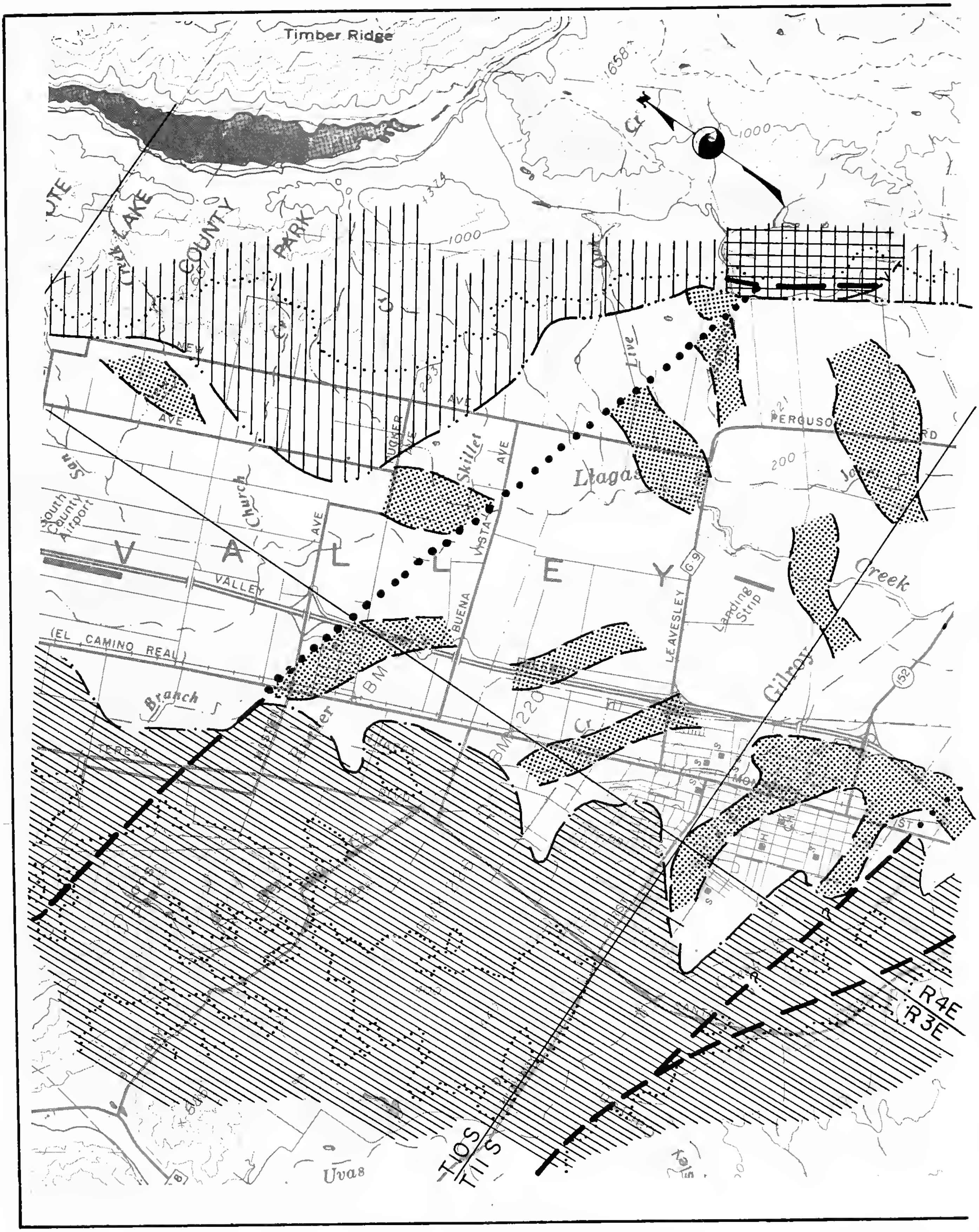
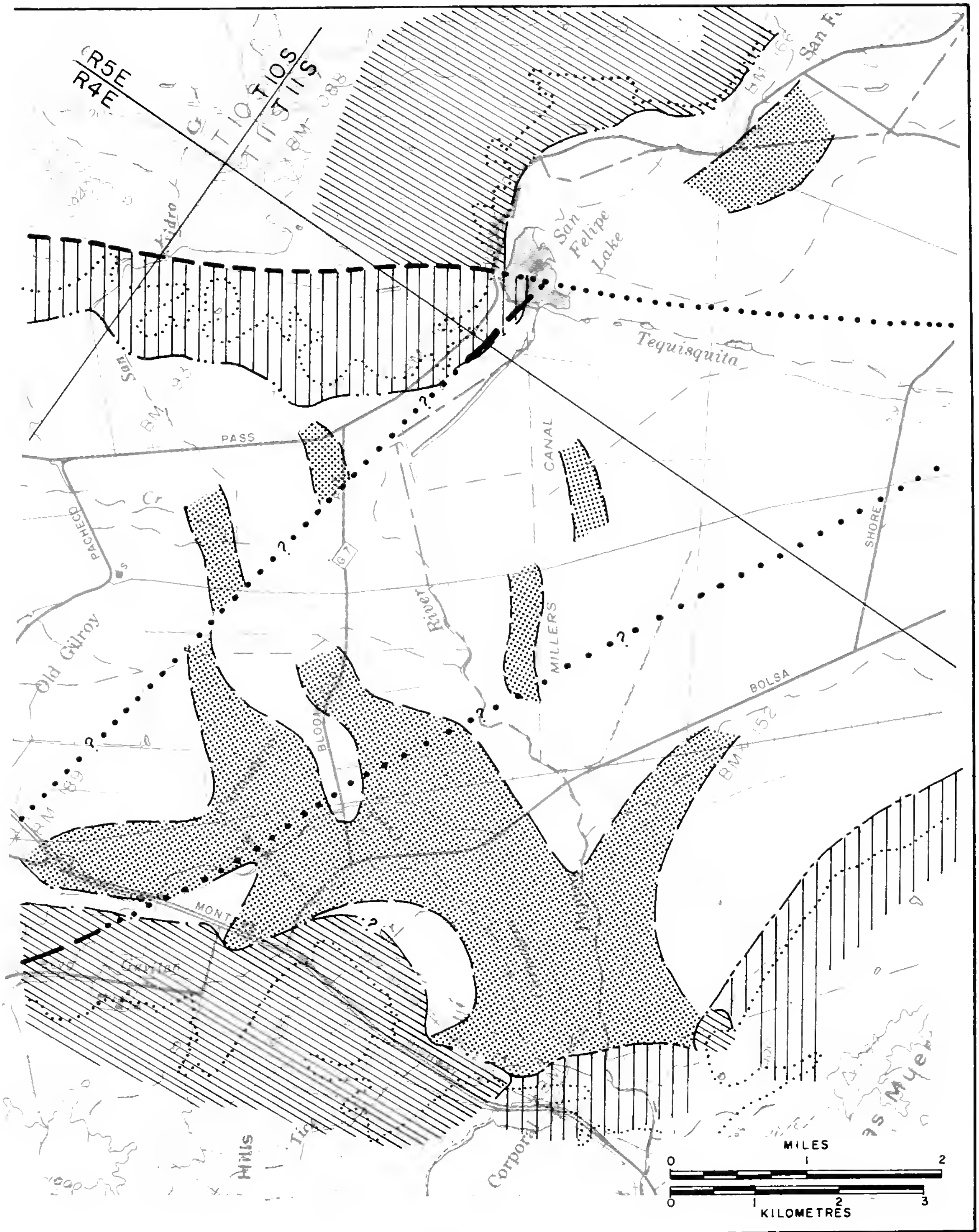


FIGURE 6J.--Subsurface Deposition, Om to



-15m, Llagas and Bolsa Subbasins.

CHAPTER III. GEOHYDROLOGY

The term "geohydrology" refers to the study of flow characteristics of subsurface waters; the term is synonymous with ground water hydrology. Geohydrology includes such topics as the occurrence, movement, and recharge of ground water, each of which is discussed below. Also included in this chapter are discussions of related topics such as the identification of the ground water basin and subbasin boundaries, water-level fluctuations, and the quality of ground water.

The Ground Water Basin

A ground water basin is defined as an area underlain by permeable materials capable of furnishing a significant supply of ground water to wells. A basin is three-dimensional and includes both its surface extent and all of its subsurface fresh-water-yielding materials. Ground water basins usually can be divided into a valley floor area and upland ground water terrain. The valley floor area normally constitutes the major part of a ground water basin, and it usually is an area of low-to-negligible relief. A valley floor area frequently can be divided into a number of subbasins. Upland ground water terrain is any contiguous upland area underlain by permeable, water-yielding materials possessing a high degree of hydrologic continuity with the valley floor area.

Ground water basins and subbasins can be separated from each other by any of the following features and conditions:

1. Impermeable Bedrock. Impermeable bedrock includes rocks of very low water-yielding capability that are usually of marine origin; it also includes crystalline and metamorphic rocks. Rocks of this category that form a part of the boundary of Santa Clara Ground Water Basin include those of the Franciscan Formation, Great Valley Sequence, Tertiary Marine Sediments, and also serpentine and related ultrabasic rocks.

2. Constriction in Permeable Materials. A narrow gap in impermeable bedrock, even though filled with permeable stream channel materials, can form a ground water subbasin boundary. Coyote Narrows is in this category, and it forms the separation between the South Santa Clara Valley and the North Santa Clara Valley.

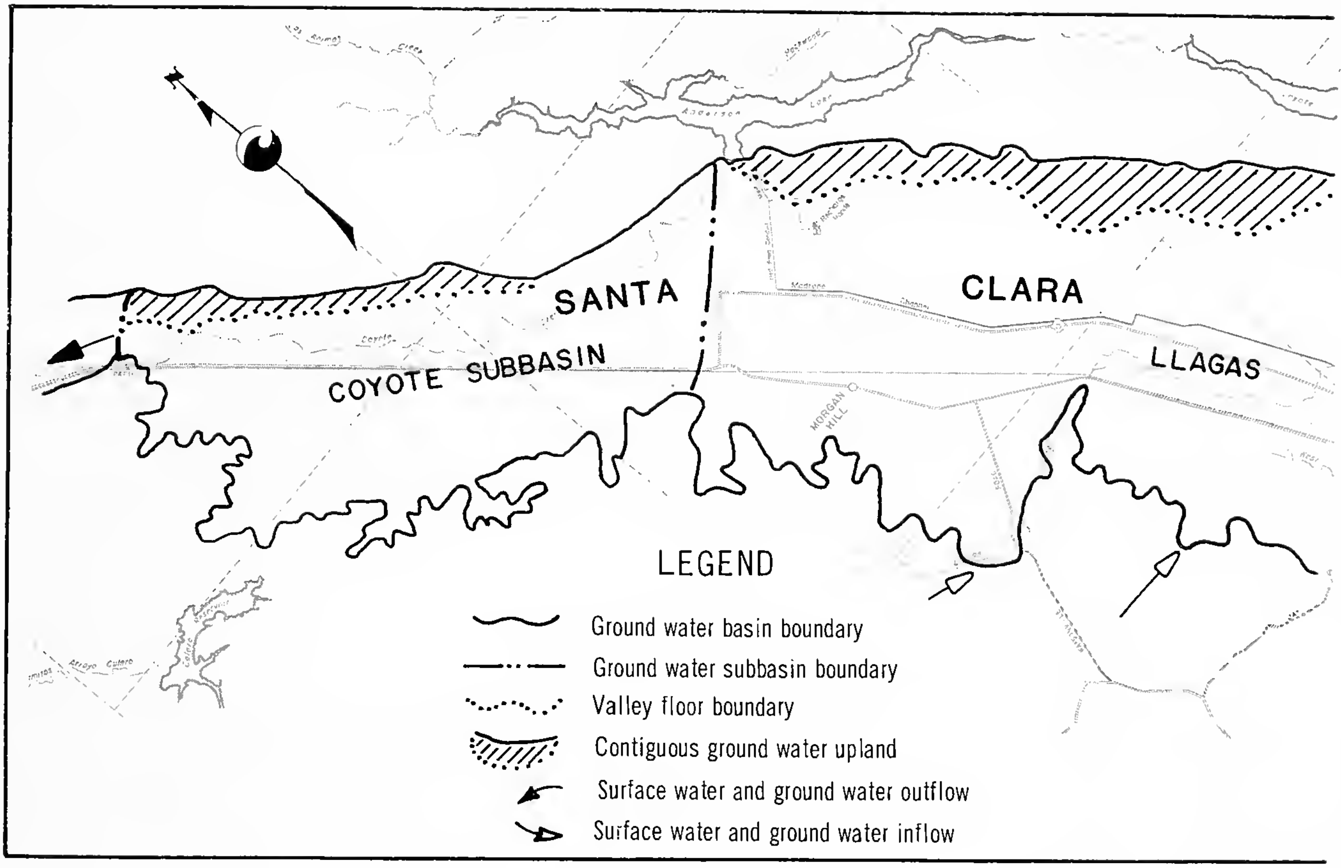


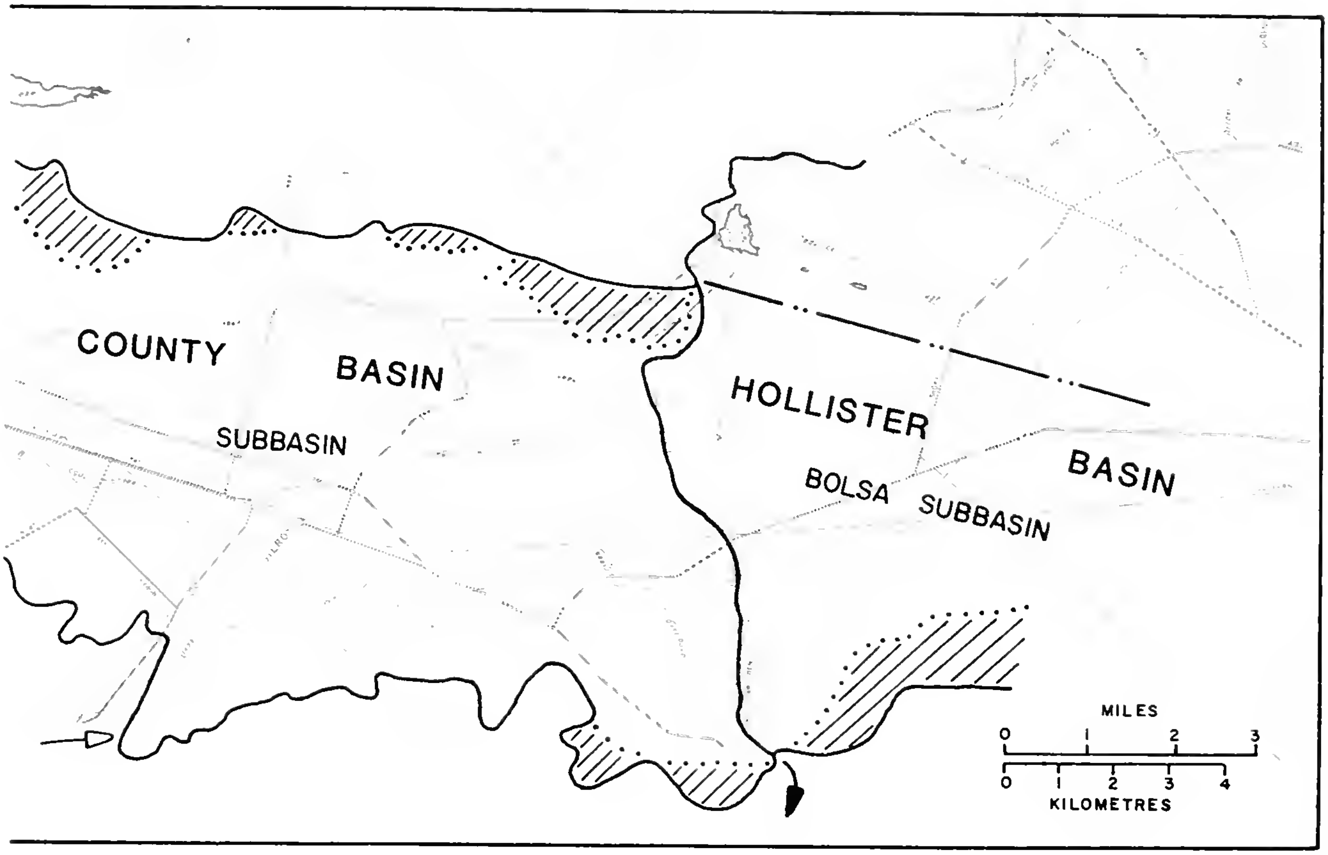
FIGURE 7.--Ground Water Basin,

3. Fault. A fault which crosses permeable materials may form a barrier to ground water movement as indicated by marked differences in water levels on either side. The Calaveras fault, where it crosses Hollister Basin, forms a ground water subbasin boundary separating the Bolsa Subbasin area from the remainder of Hollister Basin.

4. Zone of Low Permeability. A zone of clay which has significant areal and vertical extent may create a partial barrier to ground water movement and thus may form a subbasin boundary. The lacustrine clays near the Pajaro River form such a basin boundary as they impede ground water movement between the Llagas and Bolsa Subbasins.

5. Ground Water Divide. A ground water divide can form the boundary between two adjacent ground water subbasins; for example, the divide near Cochran Road, which forms the boundary between the Coyote and Llagas Subbasins.

The ground water basin, subbasin, and valley floor boundaries for the Santa Clara-Hollister Basin area are shown on Figure 7. The boundary of the present study area generally coincides with that of the valley floor area except in the Hollister Basin, where the subbasin boundary formed by the Calaveras fault is used.



Subbasin, and Valley Floor Boundaries.

The ground water basin as herein defined and as shown on Figure 7 differs markedly from that shown in two previous bulletins. This difference stems from a need to identify a geohydrologically discrete area for use in the mathematical model. The differences are enumerated below:

1. Bulletin 7: As discussed in Chapter I, State Water Resources Board Bulletin 7 (June 1955), identified two separate ground water basins in Santa Clara County: North Santa Clara Valley and South Santa Clara Valley. The boundary between these two basins was at the Cochran Road ground water divide, thus placing the present Coyote Subbasin in North Santa Clara Valley. The present study places a ground water subbasin boundary at Coyote Narrows, thus putting Coyote Subbasin in South Santa Clara Valley.

2. Bulletin 118: DWR Bulletin 118, "California's Ground Water" (September 1975), generally followed the nomenclature of Bulletin 7 and identified Ground Water Basin No. 2-9.02 as the South Bay Area of Santa Clara Valley. The areal extent of this basin extended south from San Francisco Bay to and including the present Coyote Subbasin. All of Basin No. 2-9.02 is within the San Francisco Bay Hydrologic Study Area (HSA). To the south, in the Central Coastal HSA, is Ground Water Basin No. 3-3, the

Gilroy-Hollister Valley. According to Bulletin 118, the dividing line between Basins Nos. 2-9.02 and 3-3 is at the Cochran Road ground water divide.

Water-Level Measurements, Contours, and Profiles

The determination of the occurrence, movement, and fluctuations of ground water is made through analysis of water-level data obtained from a number of key wells located throughout a ground water basin. Historic records of water level data are of great value in the determination of near-pristine hydrologic conditions. Hence, the records published by Clark in 1917 and 1924 provide insight as to ground water conditions in the South Santa Clara Valley area some 65 years ago. More recently, seasonal water level data have been collected, tabulated, and published by the Santa Clara Valley Water District (SCVWD) and its predecessor for Coyote Valley since 1936, from Coyote Valley south to San Martin since 1948, and south of San Martin since 1969. Long-term water-level data are available for only a few wells in the San Benito County portion of the study area.

Most of these water-level data are actually of a composite nature. That is, they do not represent actual potentiometric conditions for any specific aquifer or water-bearing stratum. Instead, due to construction characteristics of monitoring wells, each water-level measurement represents only an average for all water-bearing strata intercepted by a particular well. More refined data can be obtained only from wells of known depth and specific perforations or from piezometers constructed to obtain data from a specific aquifer or water-bearing stratum. A water-level monitoring network utilizing such wells and piezometers is discussed in Chapter V of this bulletin.

One interpretation of water-level data is a map depicting elevation contours on the upper surface of the ground water body. Figures 8A and 8B show such contours for fall 1914, adapted from Clark (1917) and Clark (1924), which represent the ground water body in its original unstressed condition. The same figure shows elevation contours, derived from SCVWD data, for fall 1974 and illustrates the condition of the ground water body after some 60 years of use. Figures 9A and 9B, also derived from SCVWD data, show elevation contours for fall 1977, when water levels were at their lowest due to the drought, and contours for fall 1979, which are indicative of postdrought recovery. Water level monitoring wells used to derive the elevation contours are shown on Figures 10A and 10B.

One derivative of a water-level contour map is a water-level profile, such as shown on Figure 11. This profile shows the slope of the potentiometric surface, and hence the direction of ground water movement. Shown on Figure 11 are the profiles and direction of movement for fall 1914, fall 1974, fall 1977, and fall 1979.

Ground Water Occurrence

Ground water in the South Santa Clara Valley-Hollister Basin area occurs in the alluvial materials and in the Santa Clara and Purisima Formations (see Table 1 and Figure 3). Older rocks, such as those belonging to the Franciscan Formation, are tapped only in and near the foothills and yield only minor quantities of water to wells.

The major occurrence of ground water is in the valley floor area; that is, in the area underlain by alluvial materials. These materials are underlain by the Santa Clara Formation and in the Bolsa Subbasin by the Purisima Formation. Ground water in much of the valley floor area is mostly unconfined. It occurs under essentially water-table conditions. Local areas of confinement occur, however, as indicated by water levels in certain wells that stand somewhat higher than those in nearby areas. In the subsurface, much of the ground water is partially confined. Movement of ground water is sufficiently restricted to cause slight differences in head between differing depth zones during periods of heavy pumping. During periods of little draft, however, the various water levels all recover to nearly the same level. This condition results from the lenticular and discontinuous nature of sediments where zones of permeable sand and gravel are layered between less permeable beds of silt and clay.

Coyote Subbasin

Ground water in Coyote Subbasin occurs in the valley fill materials principally under unconfined conditions. Water levels in the wells tapping the unconfined ground water body have generally been about 5 to 10 m (16 to 33 ft) below ground. Near Bailey Avenue, 1 km (0.6 mi) west of Highway 101, Clark (1924) reported two intermittently flowing wells in the 1914-1915 period. Although depth and stratigraphic data are lacking for these wells, their ability to flow during winter probably was caused by a seasonal rise in the water level coupled with local confinement.

Llagas Subbasin

Ground water in much of the Llagas Subbasin occurs under generally unconfined conditions. Local zones of confinement are present from San Martin south as noted by certain deeper wells that at one time flowed during the winter. South of Gilroy, in the area of extensive lake-bottom sediments, ground water is generally confined, and many wells originally flowed (i.e., were artesian). The potentiometric surface of the confined ground water body is now below the ground surface. To the south of Gilroy, there is also a perched to semiperched ground water body which occurs in the more permeable alluvial materials overlying extensive deposits of lake-bottom clays.

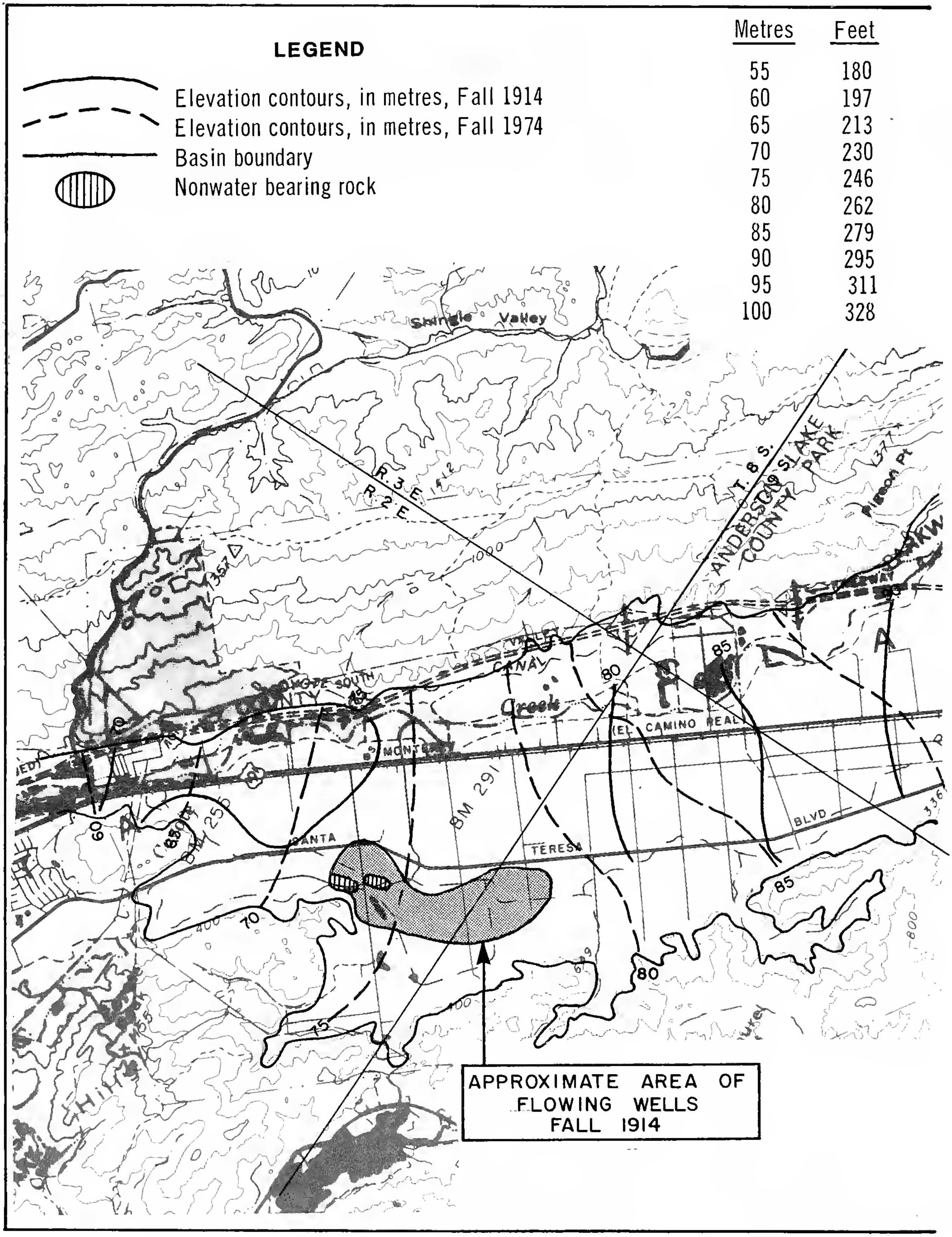
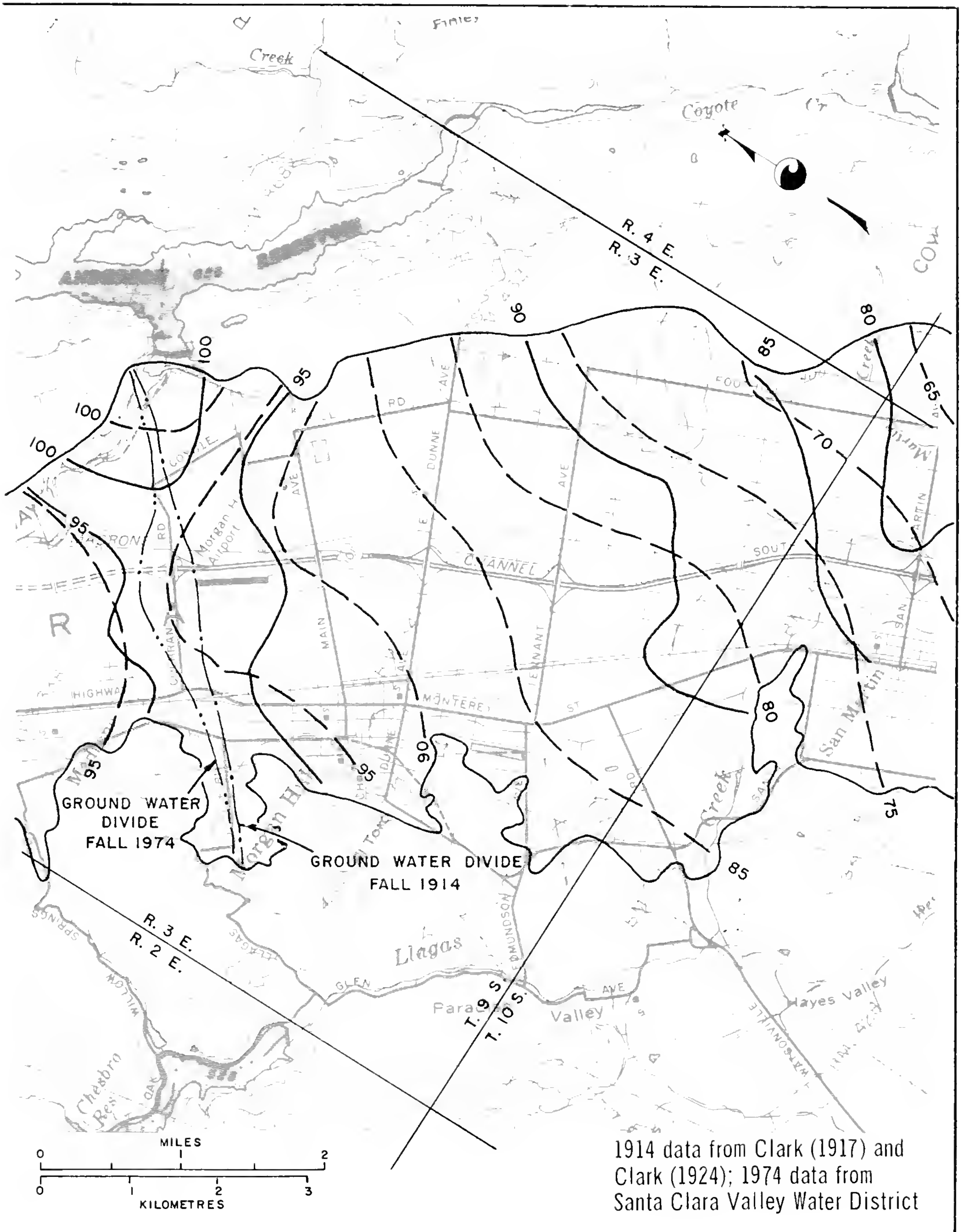


FIGURE 8A. Elevation Contours of Water Levels in Wells,



Fall 1914 and Fall 1974, South Santa Clara Valley.

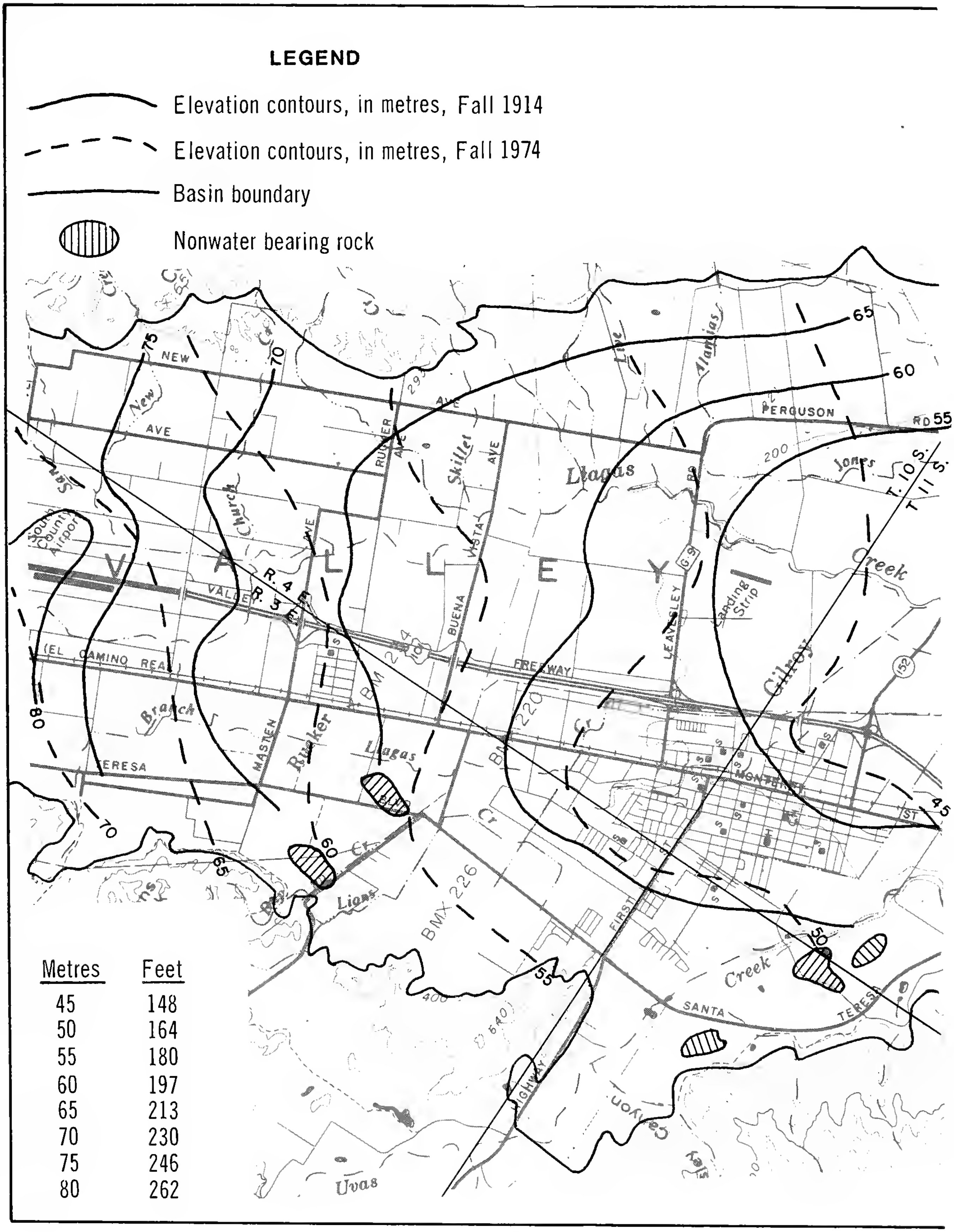
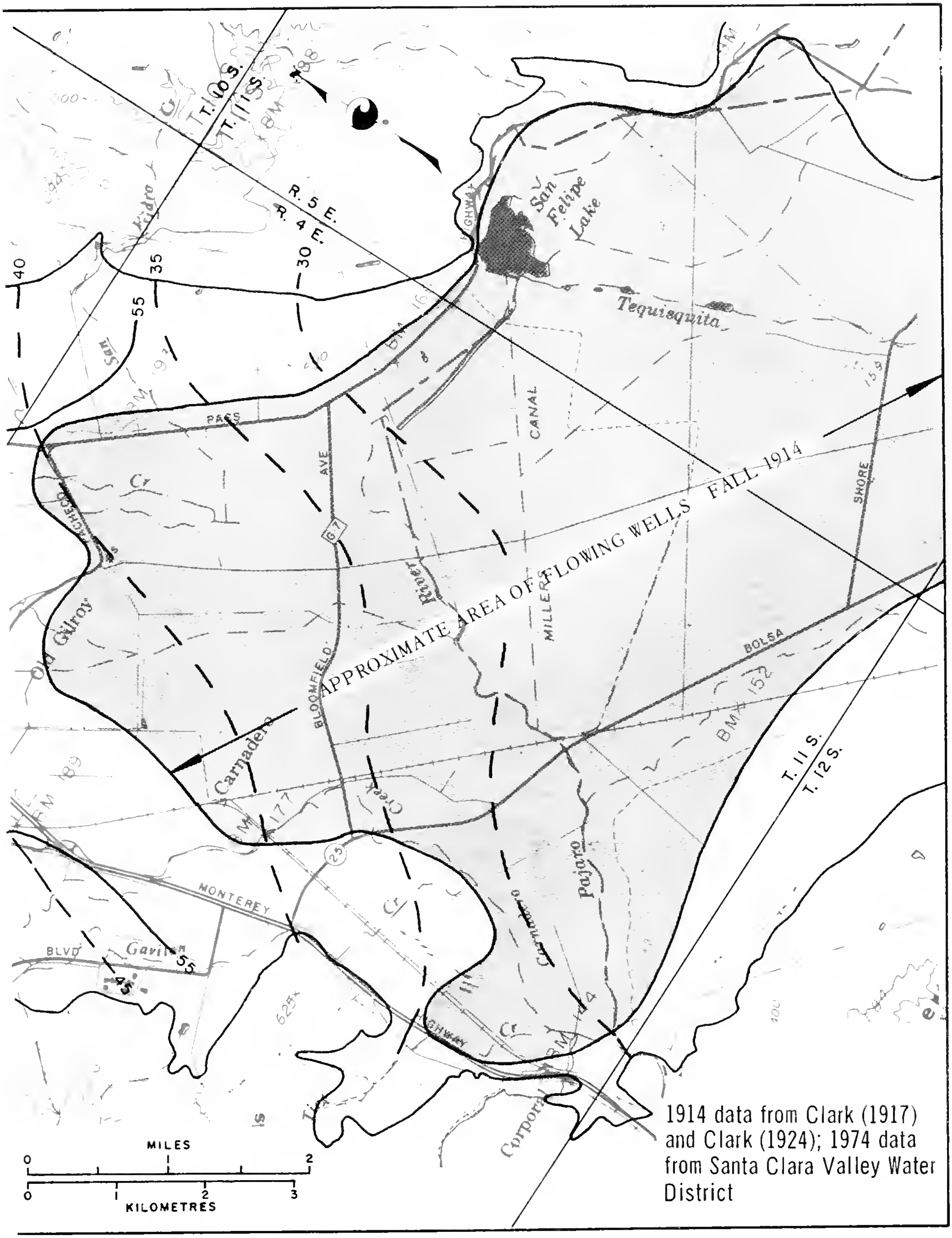


FIGURE 8B.--Elevation Contours of Water Levels in Wells,



Fall 1914 and Fall 1974, South Santa Clara Valley.

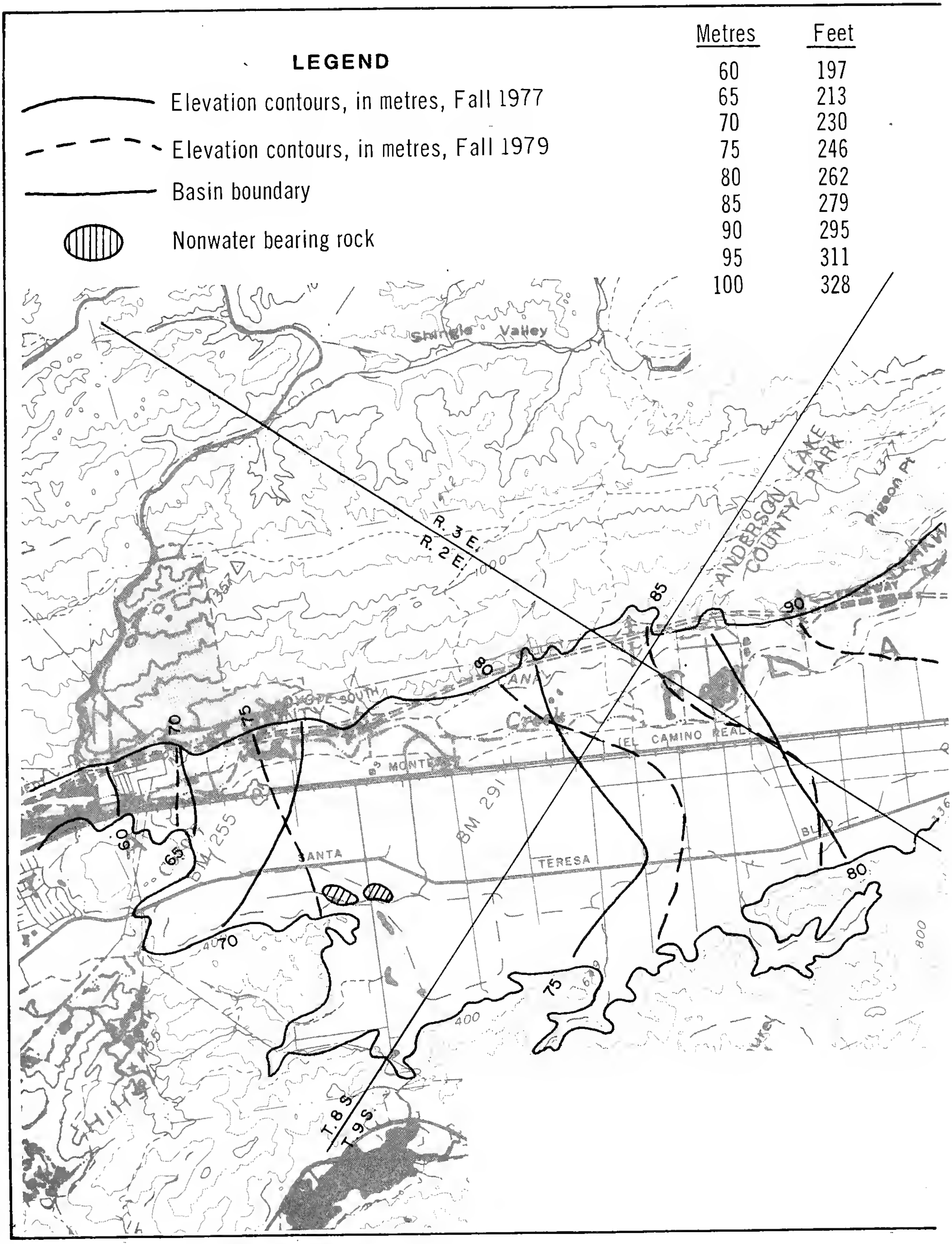
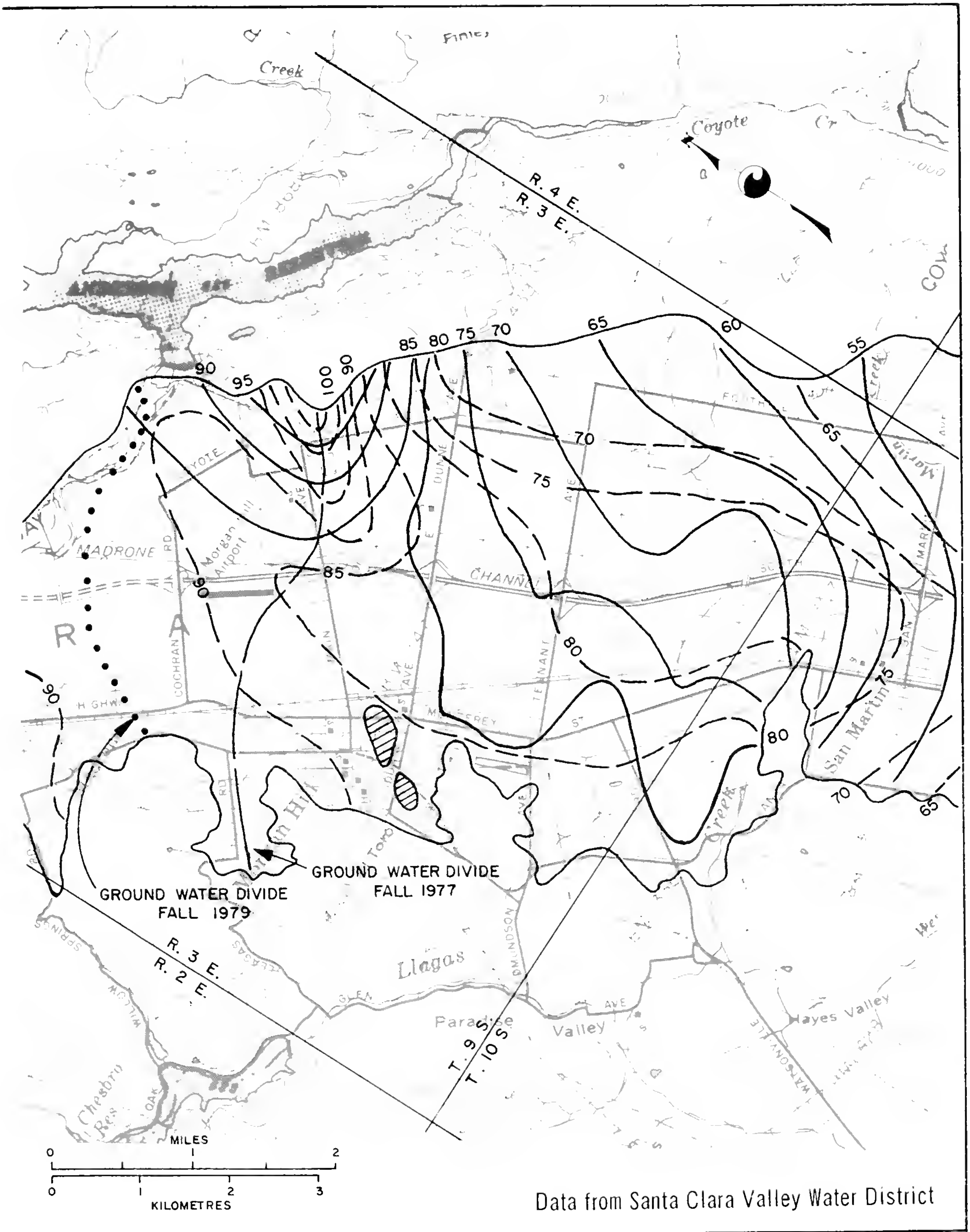
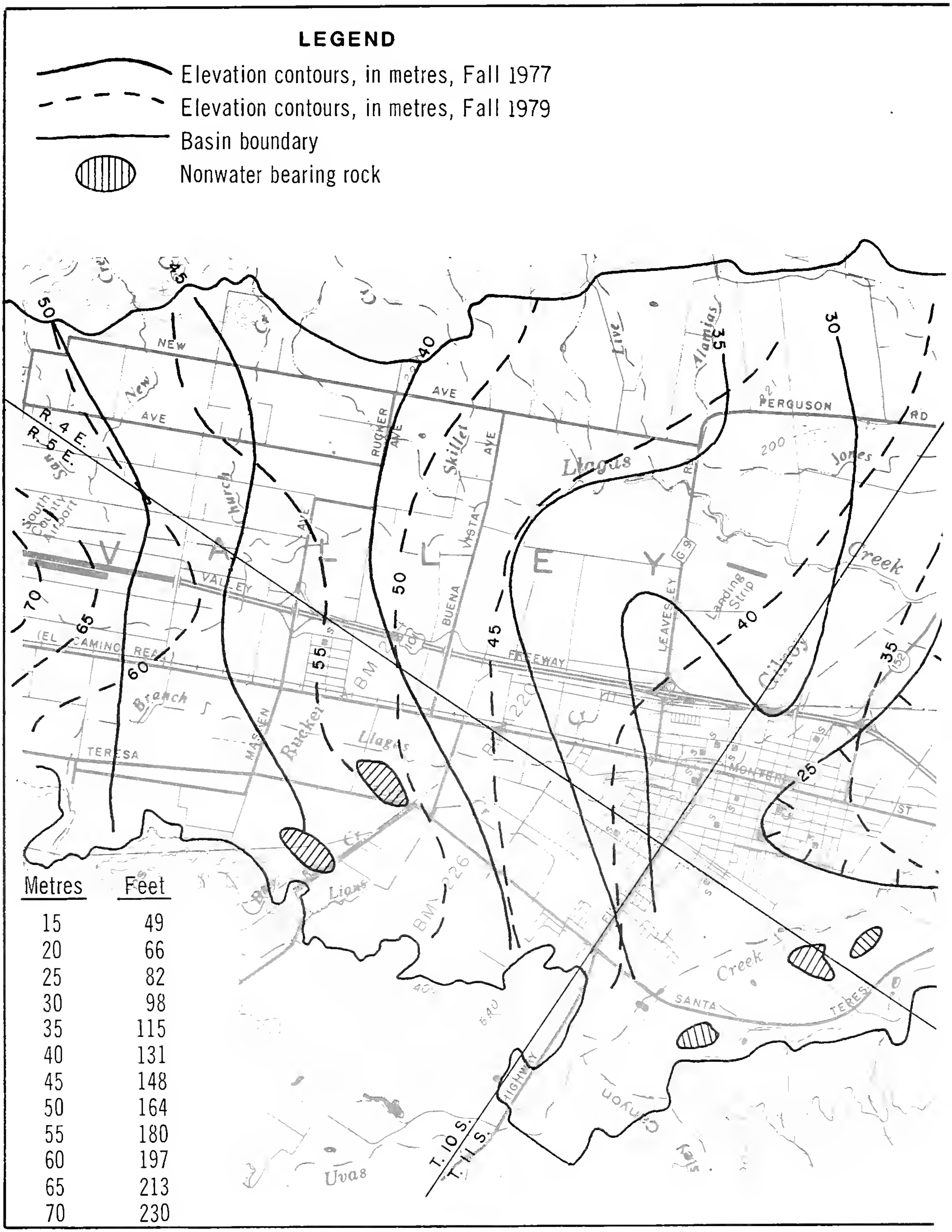


FIGURE 9A.--Elevation Contours of Water Levels in Wells,

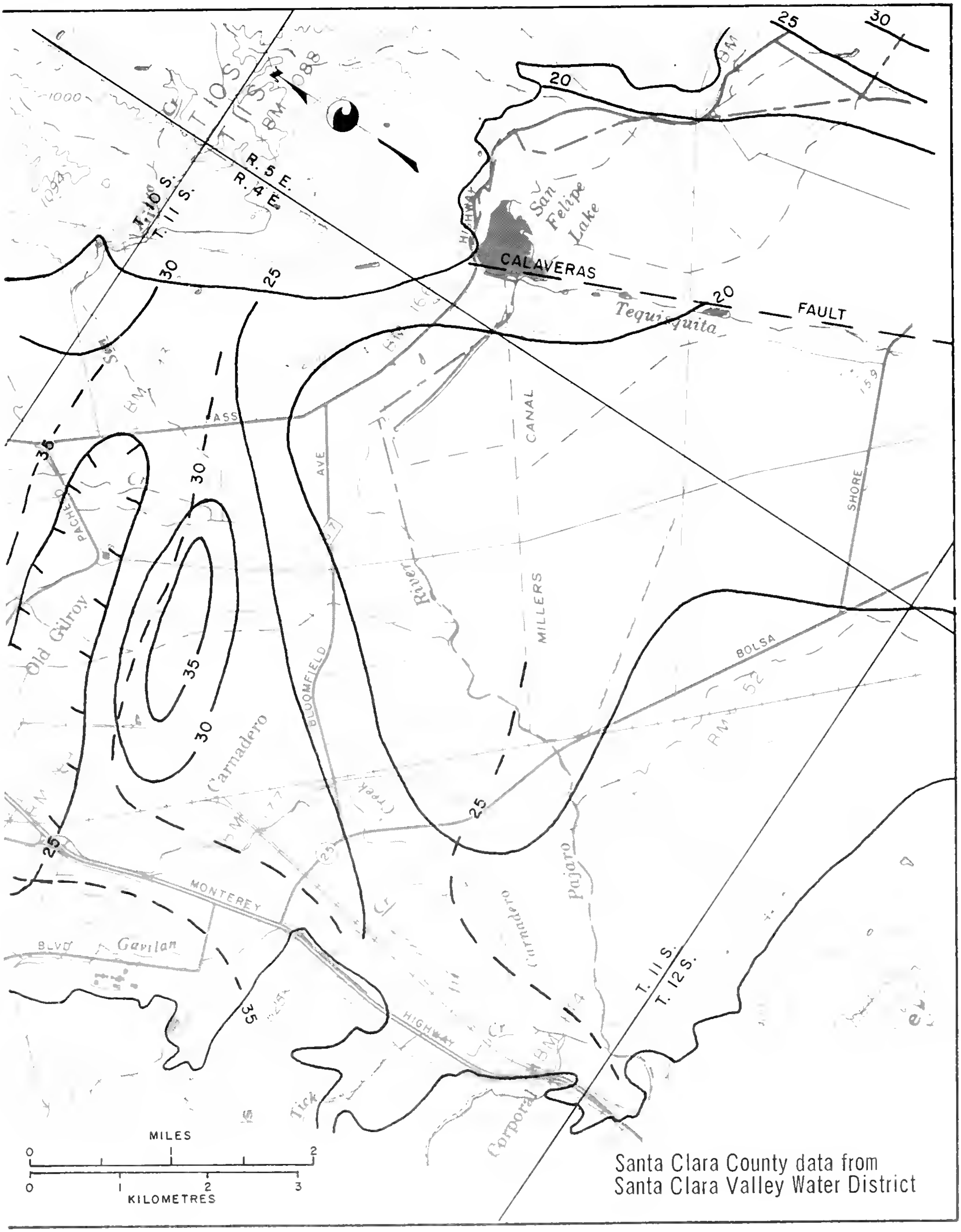


Fall 1977 and Fall 1979, South Santa Clara Valley.



Metres	Feet
15	49
20	66
25	82
30	98
35	115
40	131
45	148
50	164
55	180
60	197
65	213
70	230

FIGURE 9B.--Elevation Contours of Water Levels in Wells,



Fall 1977 and Fall 1979, South Santa Clara Valley.

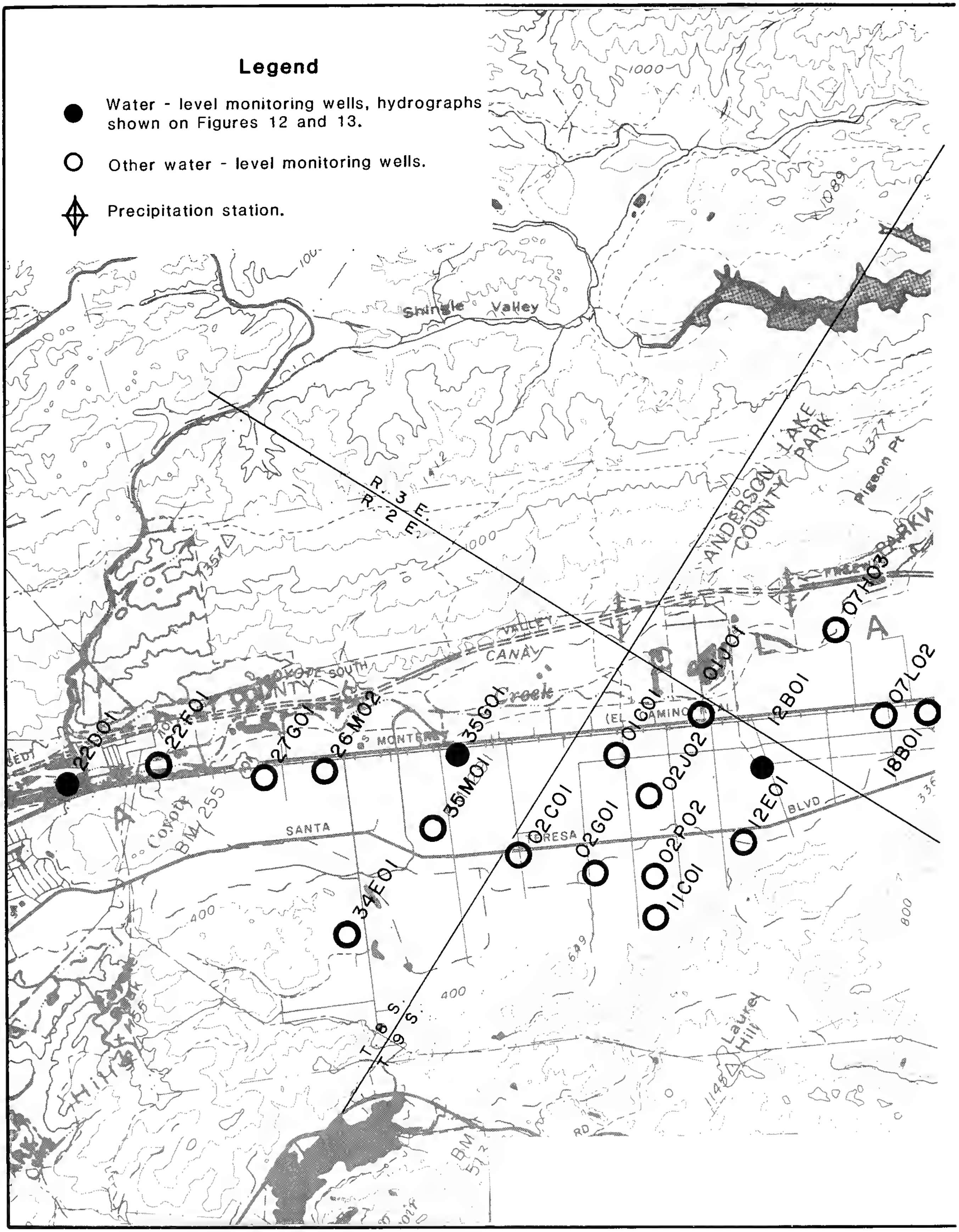
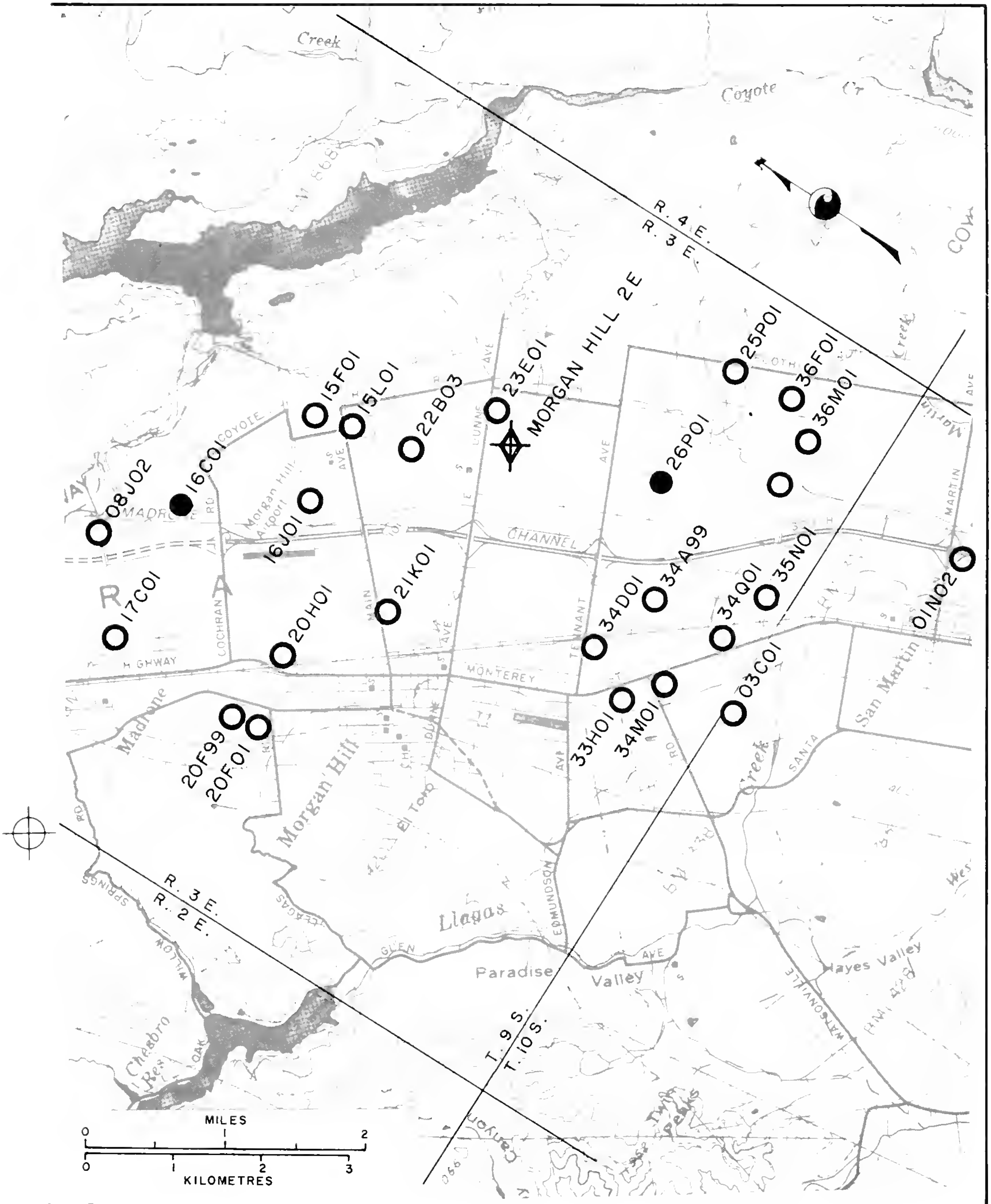


FIGURE 10A.--Water-Level Monitoring Wells and



Precipitation Stations, South Santa Clara Valley.

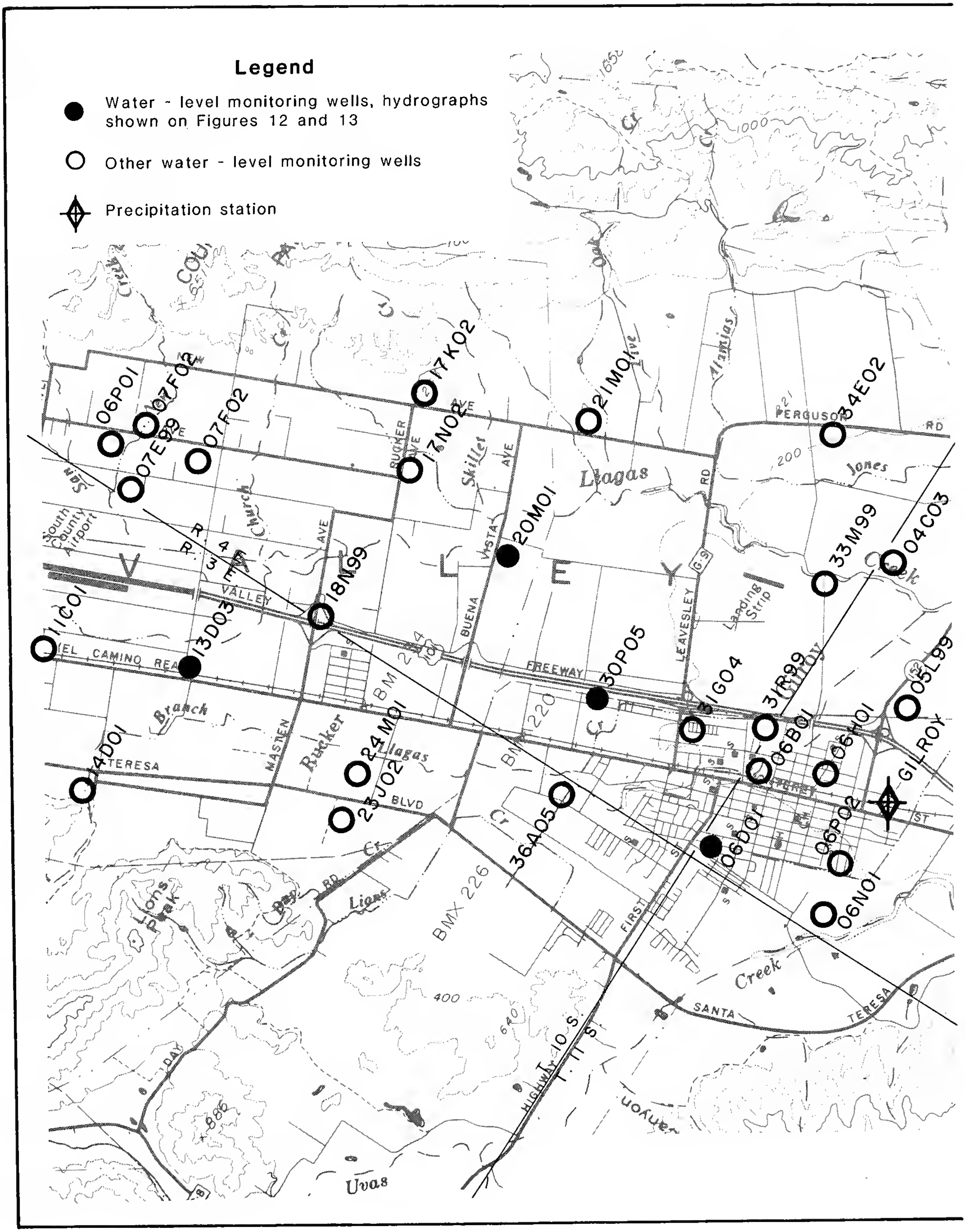
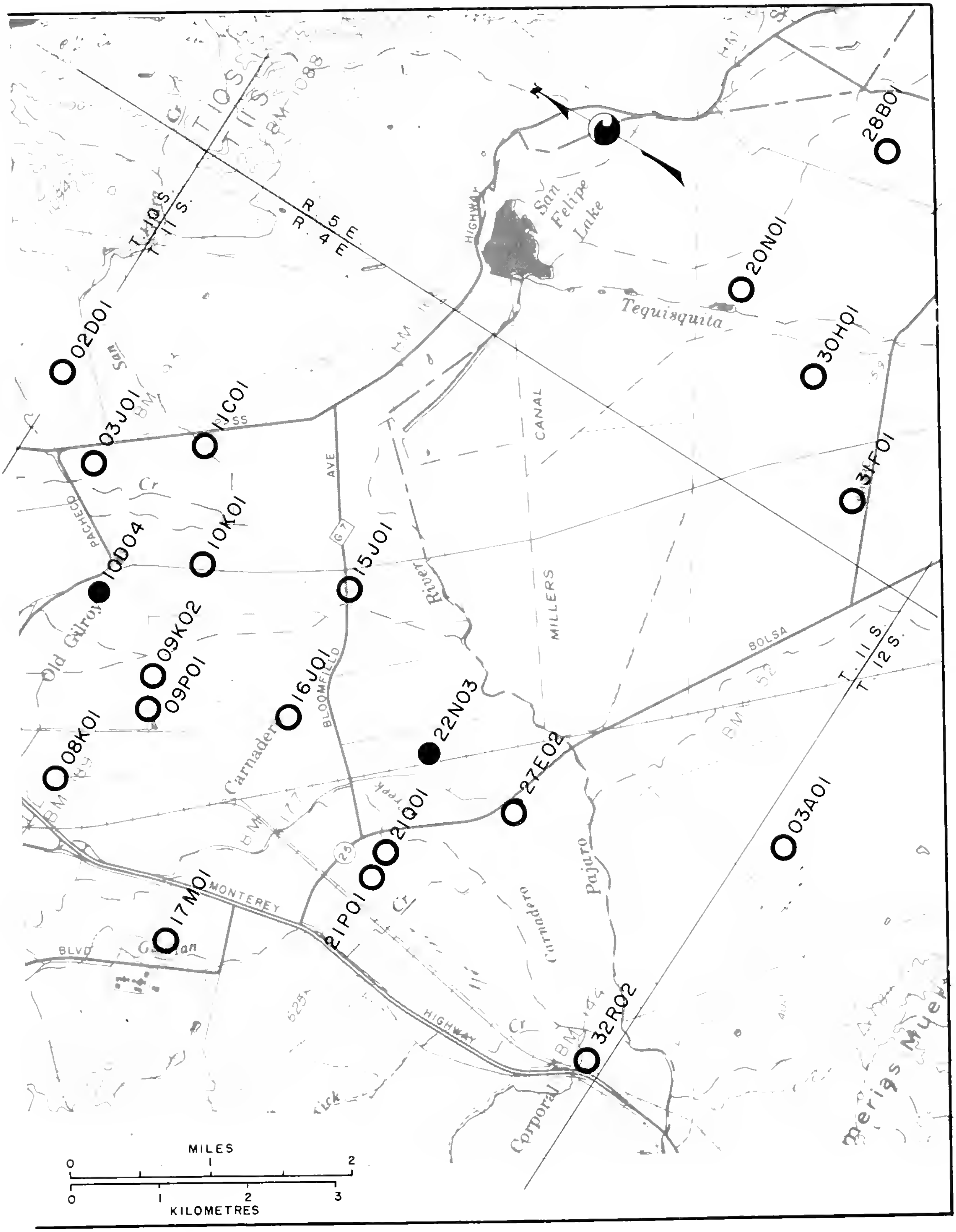


FIGURE 10B.--Water-Level Monitoring Wells and



Precipitation Stations, South Santa Clara Valley.

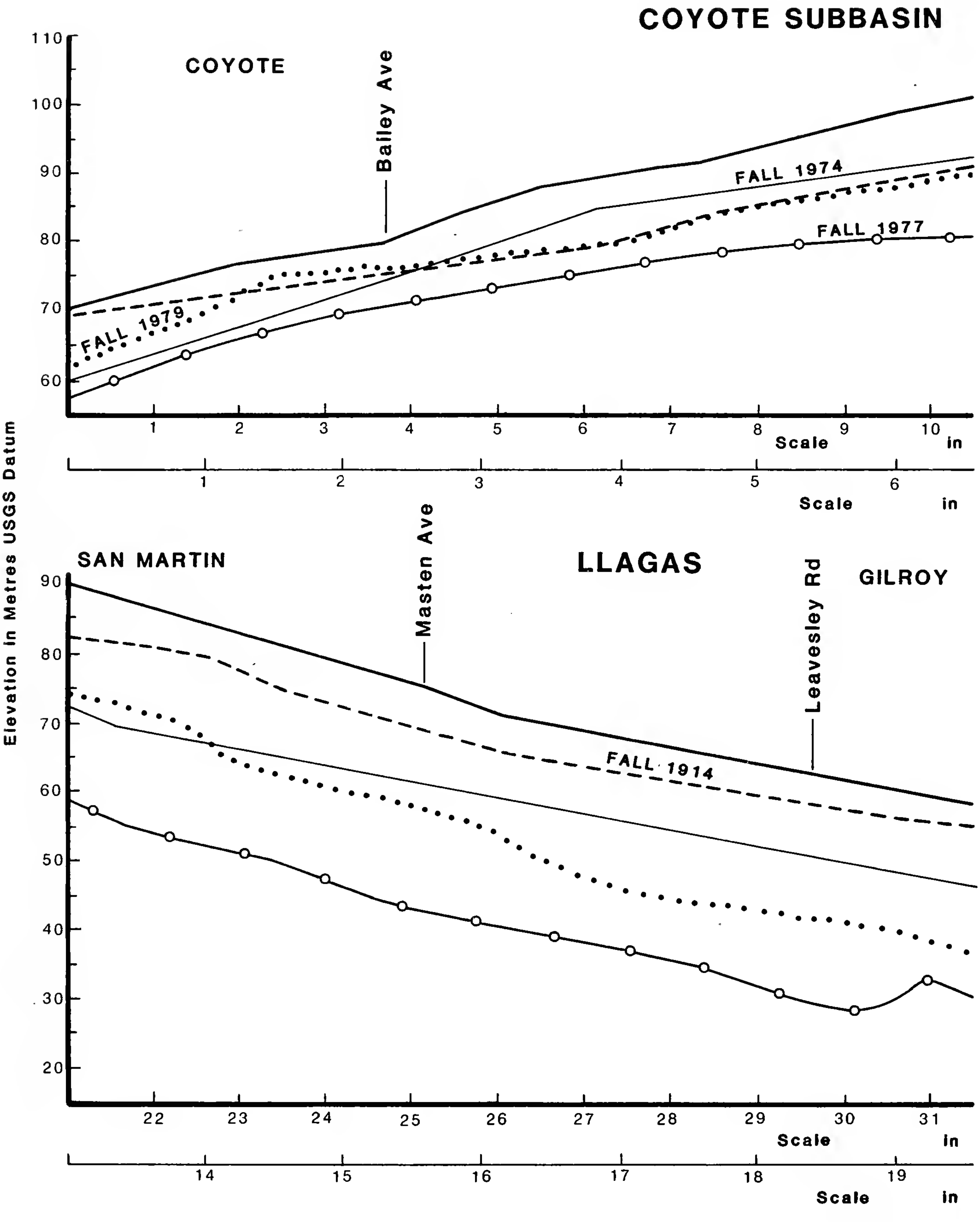
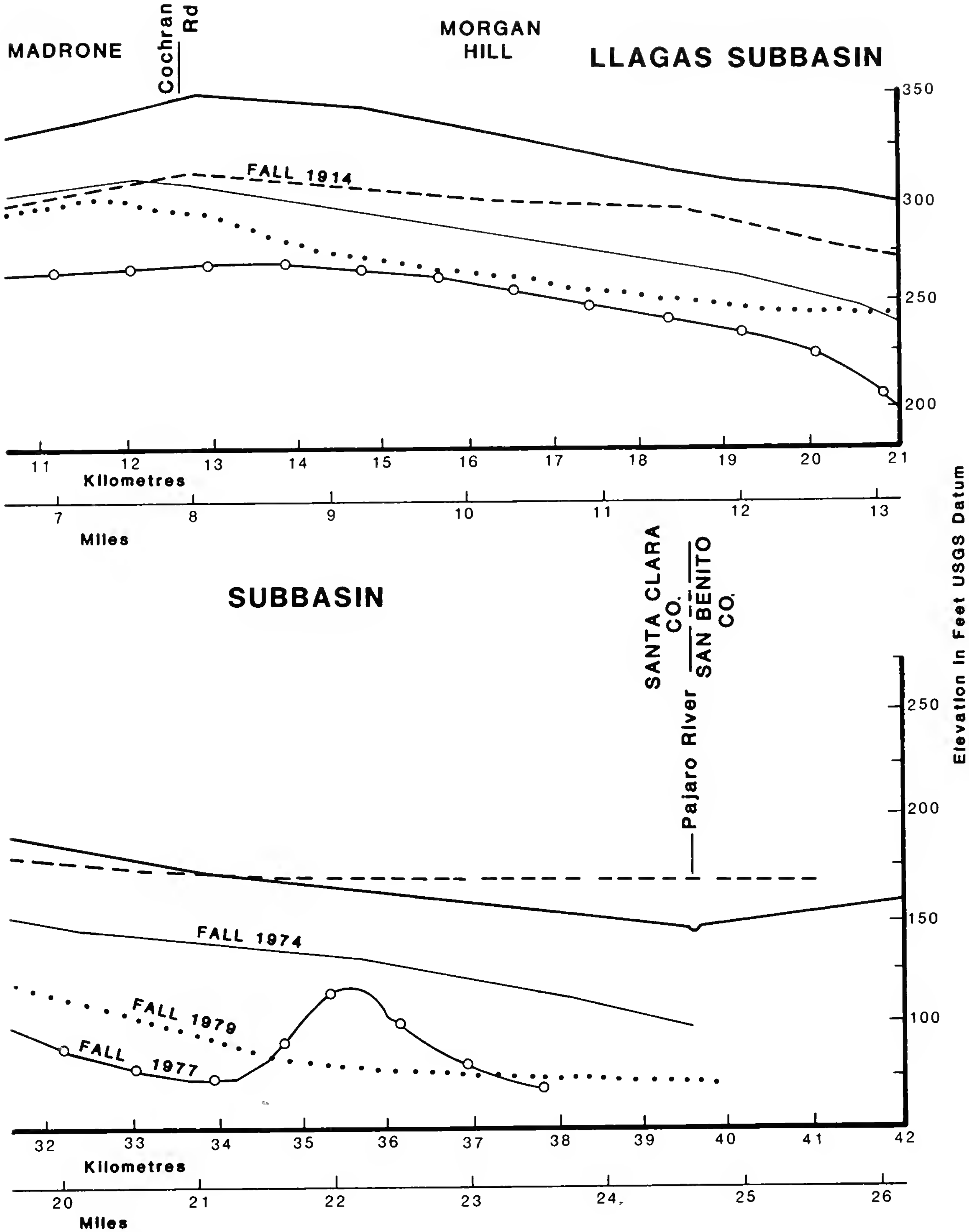


FIGURE 11.--Water-Level Profiles,



South Santa Clara Valley.

Bolsa Subbasin

Most ground water in the Bolsa Subbasin occurs in permeable materials underlying the deposits of lake-bottom clays; it is typically under various degrees of confinement. Clark (1924) identified 36 continuously flowing wells, 8 intermittently (seasonal) flowing wells, and 28 nonflowing wells in the Bolsa Subbasin during the 1915-1916 period. All of the flowing wells were located south of Shore Road. Clark identified other flowing wells to the east of the Calaveras fault, all apparently within the lakebed area of the "60-metre lake" described by Jenkins (1973) and Herd and Helley (1977).

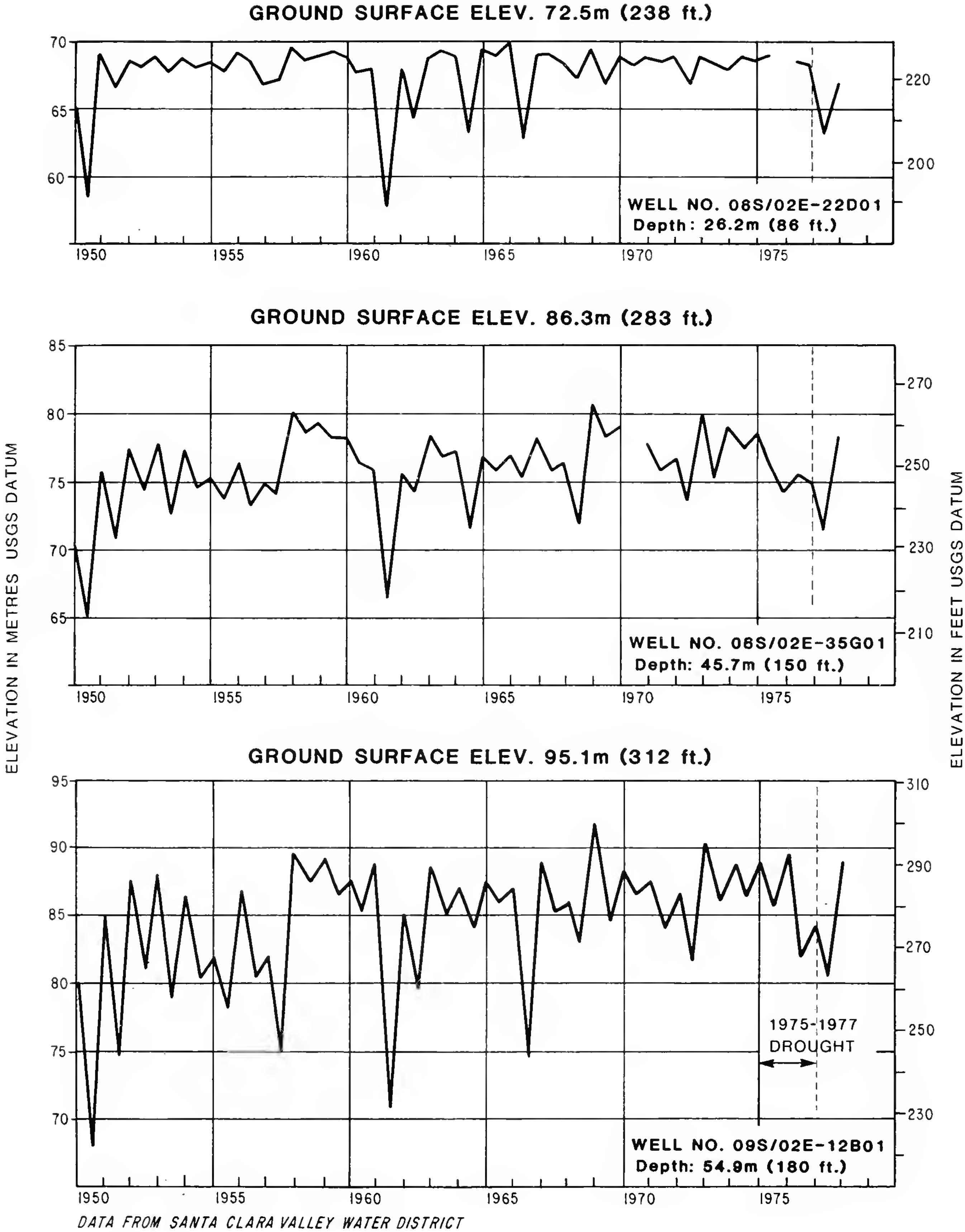
Ground Water Movement

The determination of the direction of ground water movement is made through the analysis of water-level data obtained periodically from a number of key wells located throughout a ground water basin. Many wells receive monthly measurements, and maps are prepared showing ground water elevation contours for the spring and fall of each year. Spring measurements purportedly show the configuration of the ground water surface during a time of minimum pumping; i.e., during a time when water levels stand at their highest in wells. Conversely, fall measurements ideally show the ground water surface while it is under greatest stress and water levels are at their lowest. These minimum elevations are usually attained during September and October at wells near recharge areas, after which levels begin to rise. Levels in wells more removed from recharge areas usually continue to decline an additional four to eight weeks, and minimum water level elevations are usually attained in late October or in November.

Ground water moves from areas of recharge to areas of discharge, or in the case of confined ground water, from areas of high potentiometric pressure to areas of lower pressure. Under natural conditions, ground water in the South Santa Clara Valley-Hollister Basin moved in the same direction as the surface water drainage. Hence, ground water to the north of the Cochran Road topographic divide moved northward toward Coyote Narrows, while that to the south moved toward the Pajaro River. Some upward movement of ground water occurred through windows in the various confining beds in response to hydraulic pressure differentials between the underlying ground water and the overlying unconfined ground water. Ground water still generally follows this same pattern of movement except where modified by local pumping depressions. The general direction of ground water movement is indicated on Figures 8A, 8B, 9A, 9B, and 11.

Water-Level Fluctuations

Typical water-level fluctuations in South Santa Clara Valley are shown on the hydrographs on Figures 12 and 13, which are



DATA FROM SANTA CLARA VALLEY WATER DISTRICT

FIGURE 12.--Hydrographs of Three Wells, Coyote Subbasin.

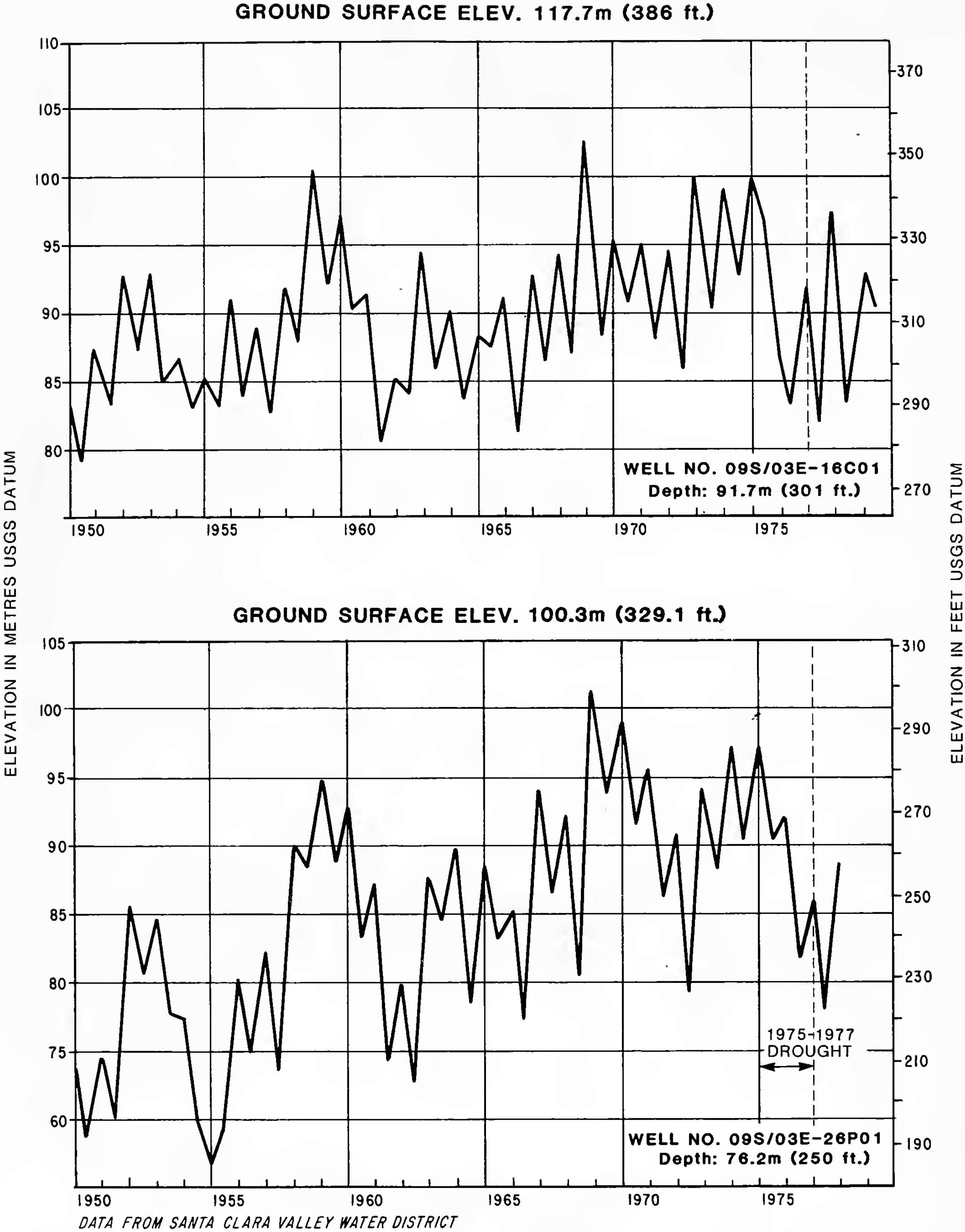
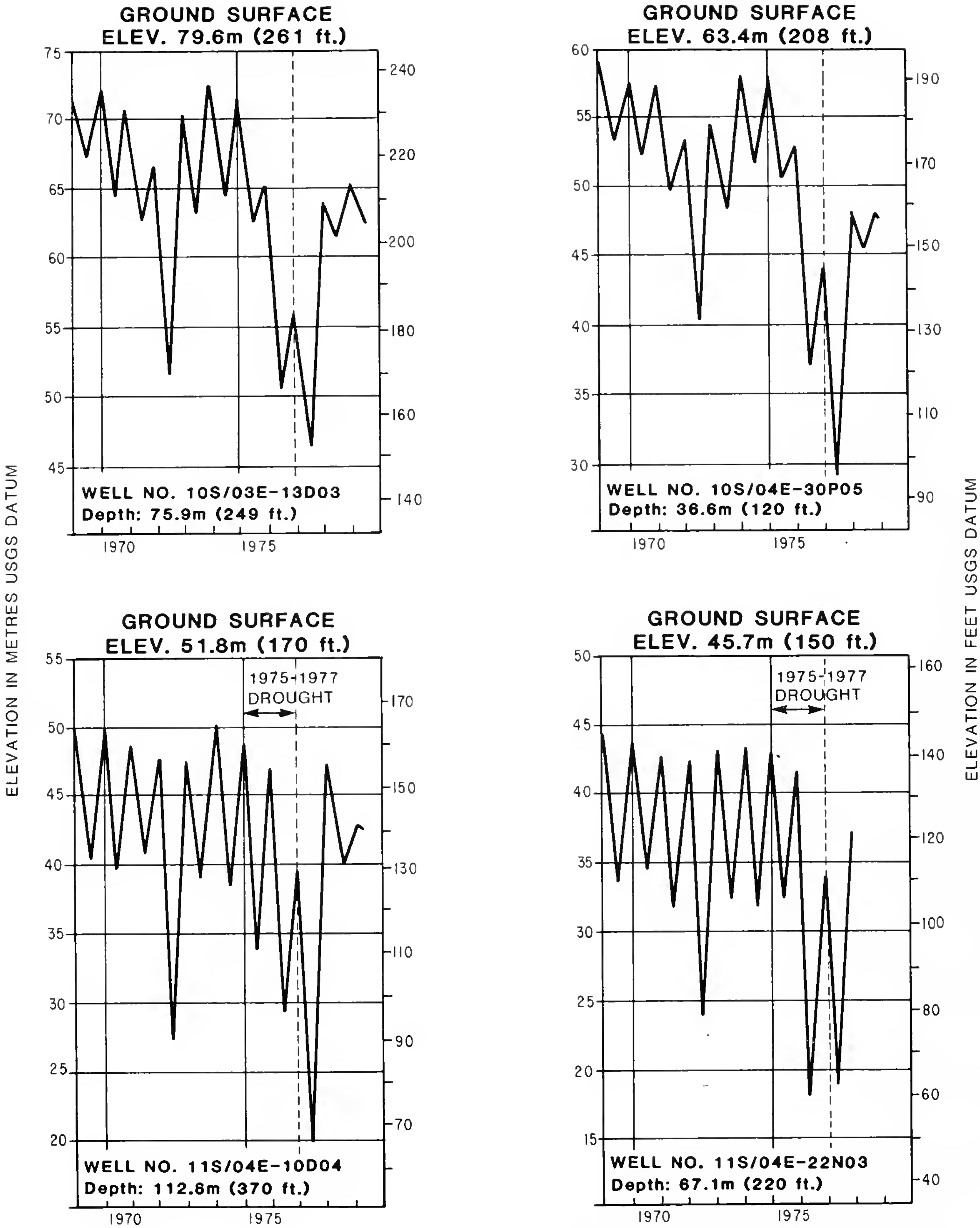


FIGURE 13.--Hydrographs of



DATA FROM SANTA CLARA VALLEY WATER DISTRICT

Six Wells, Llagas Subbasin.

representative of hydrologic conditions in unconfined and confined aquifers. The hydrographs show long-term trends as well as seasonal responses to recharge and discharge. Locations of the wells represented by the hydrographs are shown on Figures 10A and 10B.

Coyote Subbasin

During the 50-year period from 1914 to 1964, water levels declined in the Coyote Subbasin from 3 to 5 m (10 to 16 ft); the decline was probably not steady. From 1964 to 1974, levels in much of the subbasin recovered at least to 1914 levels. In fact, near Kalana Avenue, 1974 levels were 5 metres (16 ft) higher than they were in 1914. During the drought years, 1975-77, levels south of Bailey Avenue declined as much as 10 m (33 ft); in the fall of 1977 they ranged from 10 to 20 m (33 to 66 ft) below ground. North of Kalana Avenue, water levels in fall 1977 were slightly higher than they were in fall 1964, and the depth to water in fall 1977 was about 10 m (33 ft).

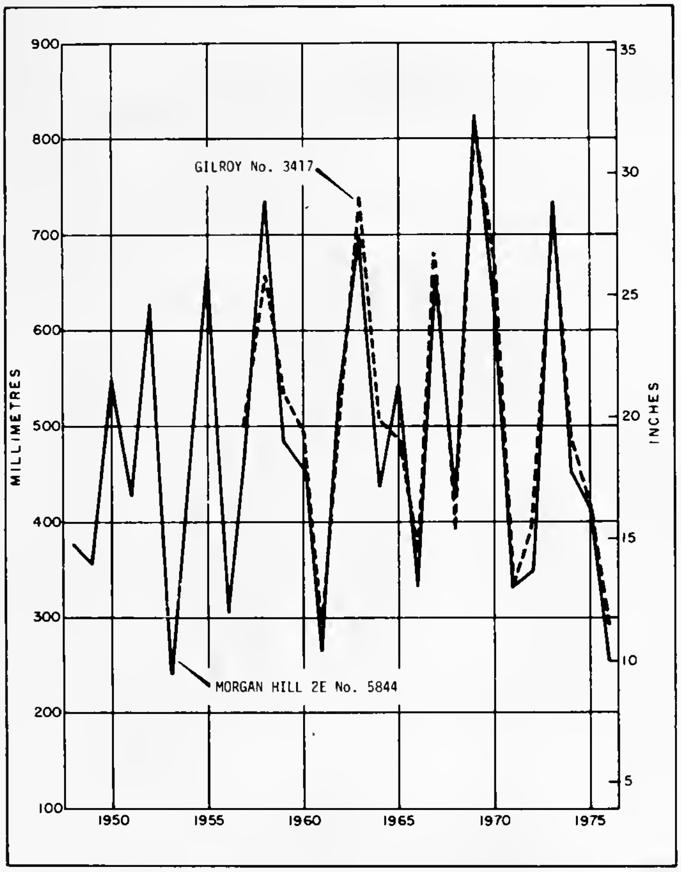


FIGURE 14.--Annual Precipitation at Two Stations, South Santa Clara Valley.

The ability of a ground water system to respond to the effects of precipitation and recharge is indicated through the comparison of well hydrographs with precipitation and streamflow data. Examination of these data for the Coyote Subbasin indicates that wells in the subbasin respond with very little lag in time. For example, the hydrographs of wells Nos. 08S/02E-22D01, 08S/02E-35G01, and 09S/02E-12B01, shown on Figure 12, indicate a dramatic water level decline in fall 1961. This decline is matched by a period of minimum precipitation recorded at the Morgan Hill 2E station, shown on Figure 14, and a zero flow in Coyote Creek during the fall of that year, as shown in Figure 15. Similar low water levels and their corresponding minimum precipitation and zero streamflows can be seen by comparing the data for fall 1964 and 1966. In contrast, somewhat higher-than-normal water levels were recorded in the three wells during spring 1969. These latter water levels correlate to a peak on the precipitation graph as well as to a high streamflow.

The 1975-77 drought had very little long-term effect on the water resource of Coyote Subbasin. By fall 1977, water levels in wells had declined to all-time lows, but after a 6-month period of above-normal rainfall and associated streamflow, water levels had recovered to predrought conditions. In some areas, water levels were higher than fall 1974 levels by as much as 3 m (10 ft).

Table 2 provides data on the postdrought water-level recovery in Coyote Subbasin. Data for a shallow well, No. 08S/02E-27G01, indicate that by spring 1978, water levels had recovered to within 0.2 m (0.7 ft) of the predrought, spring 1975 level. Data for seven wells in the 25- to 45-m (82 to 148 ft) depth range indicate that most had recovered to the spring 1975 water-level elevation. Data for seven wells from 50 to 105 m (164 to 344 ft) deep show that most had equaled or exceeded the spring 1975 level.

The lack of long-term declines in water levels in the Coyote Subbasin suggests that the subbasin is not presently stressed

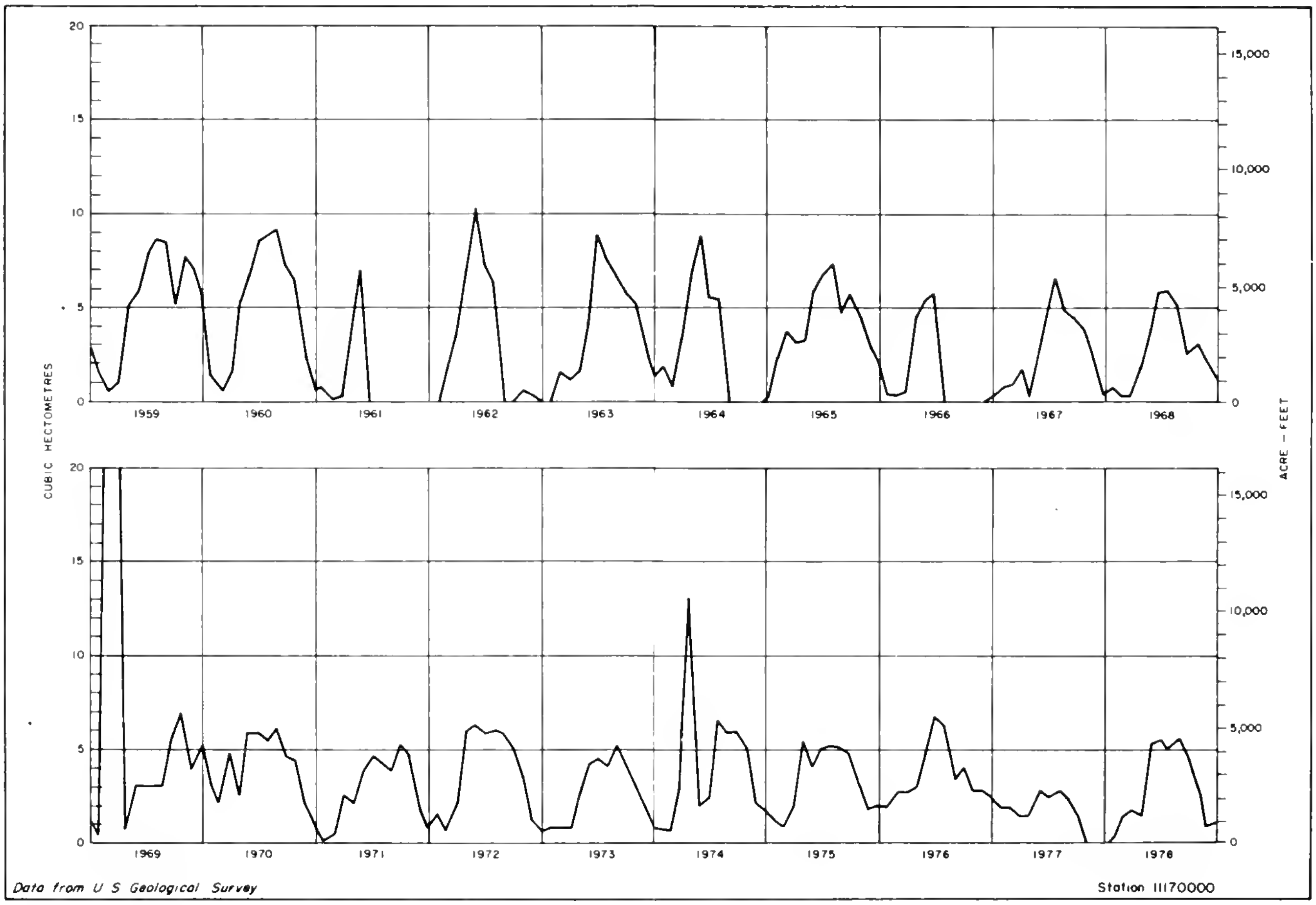


FIGURE 15.--Monthly Stream Flow, by Calendar Year, Coyote Creek near Madrone

beyond its capacity. Most of the subbasin appears to be adequately recharged by Coyote Creek; controlled releases by SCVWD from Anderson Reservoir maintain the steady flow of surface water infiltrating to the ground water body.

Llagas Subbasin

Because of the overall limited natural recharge capability of much of the Llagas Subbasin, it could become momentarily stressed due to a high dependency on ground water.

In 1914, ground water to the north of Gilroy occurred below a depth of 5 to 10 m (16 to 33 ft) below ground surface. By 1964, demand on the ground water body had sent water levels in wells to a depth of from 15 to 30 m (50 to 100 ft). In the next ten years, levels recovered somewhat, and by 1964, ground water was only about 10 to 20 m (33 to 66 ft) below ground surface.

The 1975-77 drought made a greater impact on the Llagas Subbasin than on the Coyote Subbasin. In the fall of 1977, water levels had been drawn down to an all-time low of 30 to 40 m (100 to 130 ft) below ground. According to data from water level monitoring wells, recovery from the drought was only about 75 percent complete by the spring of 1978.

Table 2 shows postdrought water-level recovery data for the Llagas Subbasin. Data from three shallow wells, all tapping essentially unconfined ground water, indicate that although water levels had recovered 11.7 m (38 ft) from the 1977 drought to spring 1978, levels still remained 11.0 m (36 ft) below those of spring 1975. The average of 28 wells in the 50- to 100-m (164 to 328 ft) depth range indicated that water levels had recovered 13.4 m (44 ft) by spring 1978, but still remained 8.7 m (29 ft) below those of spring 1975. Data from eight wells tapping confined ground water south of Gilroy indicate that although water levels came up an average of about 19 m (62 ft) by spring 1978, they still remained about 5 m (16 ft) below the spring 1975 level.

In a manner similar to that in Coyote Subbasin, monitoring wells in Llagas Subbasin show responses to major departures from the precipitation norm. For example, well No. 09S/03E-26P01 is less than 2 km (1-1/4 mi) from Morgan Hill 2E Precipitation Station. The hydrograph from the well, shown on Figure 13, indicates unusually high water levels in spring 1959 and 1969. The latter value coincides with a period of high precipitation; the former value also coincides, but with a one-year time lag. Similarly, the minimum values shown for fall 1955, 1964, 1966, 1968, and 1972 have correlatable minimum points on the precipitation chart (Figure 14); in those cases the time lag varies from one to two years.

Precipitation data from Gilroy Precipitation Station have a very rough correlation to water-level data recorded at well

Table 2. Post-Drought Water Level Recovery, South Santa Clara Valley (in metres)

Well Number	Depth	Ground Elevation	Spring 1975 Water Level		Lowest 1977 Water Level		Spring 1978 Water Level		Water-level Difference		Recovery Rate Drought 1977-Spring 1978 (Metres/Month)
			Date	Elevation	Date	Elevation	Date	Elevation	Spring 1975 to Spring 1978	Drought 1977 to Spring 1978	
COYOTE SUBBASIN											
Shallow Wells (Less than 10 metres deep)											
08S/02E-27G01	7.9	77.7	04/21	75.9	08/31	71.0	04/28	75.7	- 0.2	+ 4.7	0.59
Intermediate Wells (25 to 45 metres deep)											
08S/02E-22D01	26.2	72.5	03/19	68.7	12/01	63.5	04/04	67.3	- 1.4	+ 3.8	0.91
08S/02E-35G01	45.7	86.3	03/20	78.5	09/26	71.9	03/29	78.4	- 0.1	+ 6.5	1.06
08S/02E-35M01	27.4	80.8	03/20	79.0	09/15	72.3	03/29	78.7	- 0.3	+ 6.4	0.98
09S/02E-01C01	45.7	91.1	04/22	85.3	09/15	77.6	03/23	86.3	+ 1.0	+ 8.7	1.38
09S/02E-02J02	34.7	87.8	04/30	83.4	08/31	75.6	04/28	84.6	+ 1.2	+ 9.0	1.13
09S/02E-02P02	33.2	85.3	04/22	82.5	09/15	75.1	03/29	91.9	- 0.6	+ 6.8	1.05
09S/02E-11C01	36.6	87.2	04/22	85.8	09/26	77.0	03/29	85.6	- 0.2	+ 8.6	1.39
AVERAGE, Intermediate Wells									- 0.06	+ 7.1	1.13
Deep Wells (50 to 105 metres deep)											
09S/02E-02C01	83.8	81.7	04/21	80.1	09/26	73.0	03/29	79.5	- 0.6	+ 6.5	1.05
09S/02E-02G01	68.6	82.9	04/30	80.6	08/31	72.4	04/28	81.6	+ 1.0	+ 9.2	1.15
09S/02E-12B01	54.9	95.1	04/22	88.8	09/15	80.7	03/23	89.0	+ 0.2	+ 8.3	1.32
09S/02E-12E01	65.5	90.8	04/30	86.0	08/31	77.3	04/28	87.1	+ 1.1	+ 9.8	1.23
09S/03E-07L02	60.4	100.6	04/22	93.5	09/15	83.5	03/22	94.0	+ 0.5	+10.5	1.67
09S/03E-16C01	91.7	117.7	04/22	99.9	09/15	81.6	04/28	97.4	- 2.5	+15.8	2.11
09S/03E-18B01	102.7	100.9	03/30	95.1	12/01	84.8	03/22	95.4	+ 0.3	+10.6	2.84
AVERAGE, Deep Wells									0.0	+10.1	1.62
LLAGAS SUBBASIN											
Shallow Wells (less than 50 metres deep)											
10S/03E-01N02	40.2	86.9	04/28	78.9	11/30	55.4	03/27	65.7	-13.2	+10.3	2.64
10S/04E-07E99	48.8	87.5	04/24	73.7	09/14	49.0	06/16	63.0	-10.7	+14.0	1.55
10S/04E-30P05	36.6	63.4	04/30	57.2	09/01	29.1	04/27	48.0	- 9.2	+10.9	1.37
AVERAGE, Shallow Wells									-11.0	+11.7	1.85
Intermediate to Deep Wells (50 to 150 metres deep)											
09S/03E-15F01	76.2	121.0	04/29	111.9	11/30	87.5	03/28	105.3	- 6.2	+17.8	4.53
09S/03E-15L01	61.0	118.9	04/29	114.1	11/30	97.6	06/16	112.7	- 1.4	+15.1	2.29
09S/03E-16J01	121.9	117.3	04/29	96.7	11/30	80.7	03/28	86.4	-10.3	+ 5.7	1.45
09S/03E-20H01	73.2	107.6	04/22	97.9	11/30	83.0	03/28	90.2	- 7.7	+ 7.2	1.83
09S/03E-21K01	68.6	110.3	04/22	97.4	09/08	82.9	03/28	87.4	-10.0	+ 5.5	0.82
09S/03E-22B03	103.6	113.4	04/30	94.9	11/30	77.8	04/27	85.1	- 9.8	+ 7.3	1.48
09S/03E-23E01	128.0	110.9	04/29	90.4	11/30	71.7	03/28	81.6	- 8.8	+ 9.9	2.52
09S/03E-25P01	75.9	107.9	04/29	78.6	09/15	60.2	06/16	77.3	- 1.3	+17.1	1.87
09S/03E-26P01	76.2	100.3	03/21	88.2	09/15	68.0	03/27	78.8	- 9.4	+10.8	1.62
09S/03E-33H01	115.8	96.0	04/28	86.3	09/14	66.3	03/27	76.1	-10.2	+ 9.8	1.51
09S/03E-34D01	114.3	99.7	05/01	90.8	09/01	67.1	04/27	82.9	- 7.9	+15.8	1.98
09S/03E-34N01	57.3	93.9	04/28	88.7	11/30	69.9	03/27	80.2	- 8.4	+10.3	2.64
09S/03E-34Q01	59.4	95.7	04/28	90.3	11/30	71.3	03/27	82.8	- 7.5	+11.5	2.95
09S/03E-36F01	144.8	98.1	04/29	78.1	11/29	57.0	03/27	64.5	-13.6	+ 7.5	1.91
09S/03E-36M01	61.0	94.5	04/29	82.2	09/15	61.2	03/27	69.9	-12.3	+ 8.7	1.35
10S/03E-03C01	67.1	107.6	04/28	100.7	09/26	80.8	03/27	93.9	- 6.8	+13.1	2.16
10S/03E-13D03	75.9	79.6	04/30	71.7	09/30	46.0	04/27	64.4	- 7.3	+18.4	2.64
10S/03E-23J02	78.6	71.6	04/24	68.9	09/12	44.2	05/30	58.8	-10.1	+14.6	1.87
10S/03E-36A05	64.6	63.7	03/24	56.9	11/28	34.0	03/22	44.1	-12.8	+10.1	2.66
10S/04E-17K02	76.2	90.2	04/24	63.0	09/01	38.5	05/30	51.5	-11.5	+13.0	1.43
10S/04E-20M01	64.3	67.1	04/28	60.8	09/14	34.0	05/31	50.5	-10.3	+16.5	1.91
10S/04E-31G04	100.0	60.7	04/01	52.2	08/12	43.0	05/25	43.0	- 9.2	+17.4	1.83
11S/04E-02D01	86.9	69.8	04/01	51.8	09/01	14.1	04/27	43.6	- 8.2	+29.5	3.70
11S/04E-03J01	126.5	59.7	03/24	51.3	09/26	26.5	03/23	40.4	-10.9	+13.9	2.34
11S/04E-06D01	143.3	63.7	04/01	49.7	09/02	25.3	05/25	43.3	- 6.4	+18.0	2.04
11S/04E-06H01	105.5	59.1	04/01	50.6	09/02	23.7	05/25	42.0	- 8.6	+18.3	2.07
11S/04E-06P02	92.0	62.2	04/01	51.2	09/02	24.1	05/25	43.0	- 8.2	+18.9	2.14
11S/04E-11C01	131.1	53.3	03/24	49.0	09/26	25.5	03/23	39.9	- 9.1	+14.4	2.43
AVERAGE, Intermediate to Deep Wells									- 8.7	+13.4	2.11
Wells in Area of Lakebed Clay--Confined Ground Water (20 to 115 metres deep)											
11S/04E-08K01	---	54.3	03/21	45.1	09/13	23.9	03/22	36.3	- 8.8	+12.4	1.96
11S/04E-10D04	112.8	51.8	04/01	49.5	09/01	19.6	04/27	47.8	- 1.7	+28.2	3.54
11S/04E-15J01	---	43.9	03/24	44.6	09/15	24.3	03/22	38.8	- 5.8	+14.5	2.31
11S/04E-17M01	24.4	54.9	03/31	50.0	11/28	30.8	03/22	41.2	- 8.8	+10.4	2.74
11S/04E-21P01	---	47.2	04/01	45.1	09/01	14.2	04/27	42.2	- 2.9	+28.0	3.51
11S/04E-21Q01	---	47.2	03/31	43.9	08/01	16.8	03/30	38.1	- 4.8	+21.3	2.64
11S/04E-22N03	67.1	45.7	03/31	43.4	09/13	19.0	03/22	37.4	- 6.0	+18.4	2.91
11S/04E-27E02	---	44.2	03/31	42.7	08/03	16.8	03/22	36.9	- 5.8	+20.1	2.61
11S/04E-32R02	---	42.7	03/31	40 8	09/26	20.4	03/22	36.6	- 4.2	+16.2	2.75
AVERAGE, Wells in Area of Lakebed Clay									- 5.4	+18.8	2.77

No. 10S/04E-30P05, shown on Figure 13. This 37-m (120-ft) deep well appears to have about a one-year response lag to maximum and minimum precipitation. Nearby well No. 11S/04E-06D01 has only minimal correlation; this is probably due to the fact that the well is 143 m (470 ft) deep and taps confined ground water. The hydrograph of well No. 11S/04E-10D04 indicates that confined ground water shows little response to changes in precipitation; the well is in the area of lakebed clays. Seasonal fluctuations in precipitation prior to the 1975-77 drought caused only a slight water level fluctuation in the well. The low precipitation period of 1971-72 apparently caused a lowering of levels during fall 1972, but levels returned to near normal the next spring. The 1976-77 drought, however, again caused a lowering of fall levels in the well.

It was not possible to determine the degree of water level response attributable to fluctuations of streamflows in Llagas or Uvas Creeks. The flows, which are shown on Figure 16, occur mostly during the nonirrigation winter months. During a very few years, 1974 on Llagas Creek for example, minor streamflows occurred during the irrigation season. Some of this flow may have infiltrated and sustained water levels in nearby wells. Because much of the ground water in this area exists under confined conditions, water level responses in wells are greatly affected by pumping of other wells tapping the same system.

Bolsa Subbasin

Only a minimum of water-level data are available for the Bolsa Subbasin. Clark made no attempt during the 1914-1916 study to determine the elevation of the pressure surface at any of the flowing wells. Water-level data are available from five wells for fall 1974 and 1977. These data indicate that the ground water depression identified by Kilburn (1972) continues to exist. The depth to water at Shore Road in fall 1974 was 37.7 m (124 ft); in fall 1977, it was only 33.0 m (108 ft), which might be attributable to a slight increase in potentiometric pressures in some of the confined aquifers rather than an actual rise in water levels in an unconfined aquifer. Conversely, at a well located 2 km (1.2 mi) south of Shore Road, the depth to water in fall 1974 was 33.3 m (108 ft) and 44.5 m (146 ft) in fall 1977. This drop of the potentiometric surface may have been due to a decrease in pressure in the underlying confined aquifers.

Ground Water Recharge

Recharge to the ground water body is derived from the following five sources: natural recharge along streams, seepage along canals and other waterways, deep percolation of precipitation and excess irrigation water, artificial recharge, and subsurface inflow from the Santa Clara Formation (often called "hidden recharge"). The amount of water recharged to the ground water

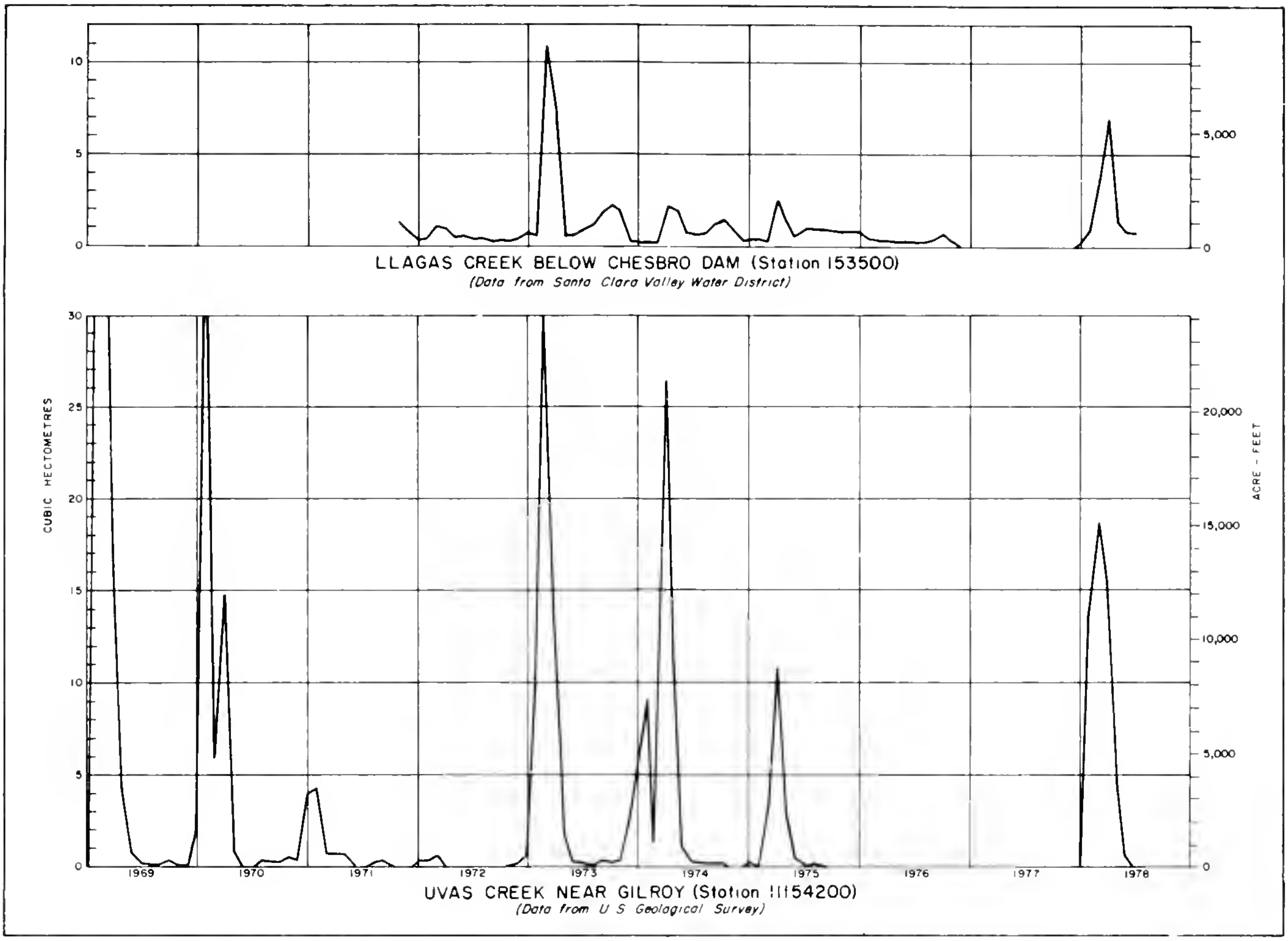


FIGURE 16.--Monthly Stream Flow, by Calendar Year, Llagas Subbasin Streams.

body from these different sources varies widely from year to year, as the controlling factor in most areas is precipitation. In years of abundant precipitation and its resultant runoff, recharge is large; conversely, in dry years such as the 1977 drought, there is little precipitation, little runoff, and consequently little recharge other than that derived from reservoir releases.

Ground water in Coyote Subbasin is recharged principally by Coyote Creek. Flow in the creek, which is maintained by releases from Anderson Reservoir, infiltrates the streambed to recharge to the ground water body. A lesser amount of recharge also is afforded from several streams draining the mountainous area to the west.

In Llagas Subbasin, natural recharge is afforded by Llagas and Uvas Creeks, which enter the subbasin from the west. Coyote Creek provides little direct natural recharge to this subbasin; however, some Coyote Creek water, after infiltrating to the ground water body, may percolate laterally and move into the subbasin by way of subsurface inflow. The Pajaro River, although flowing about 10 km (16 mi) along the southern boundary of the subbasin,

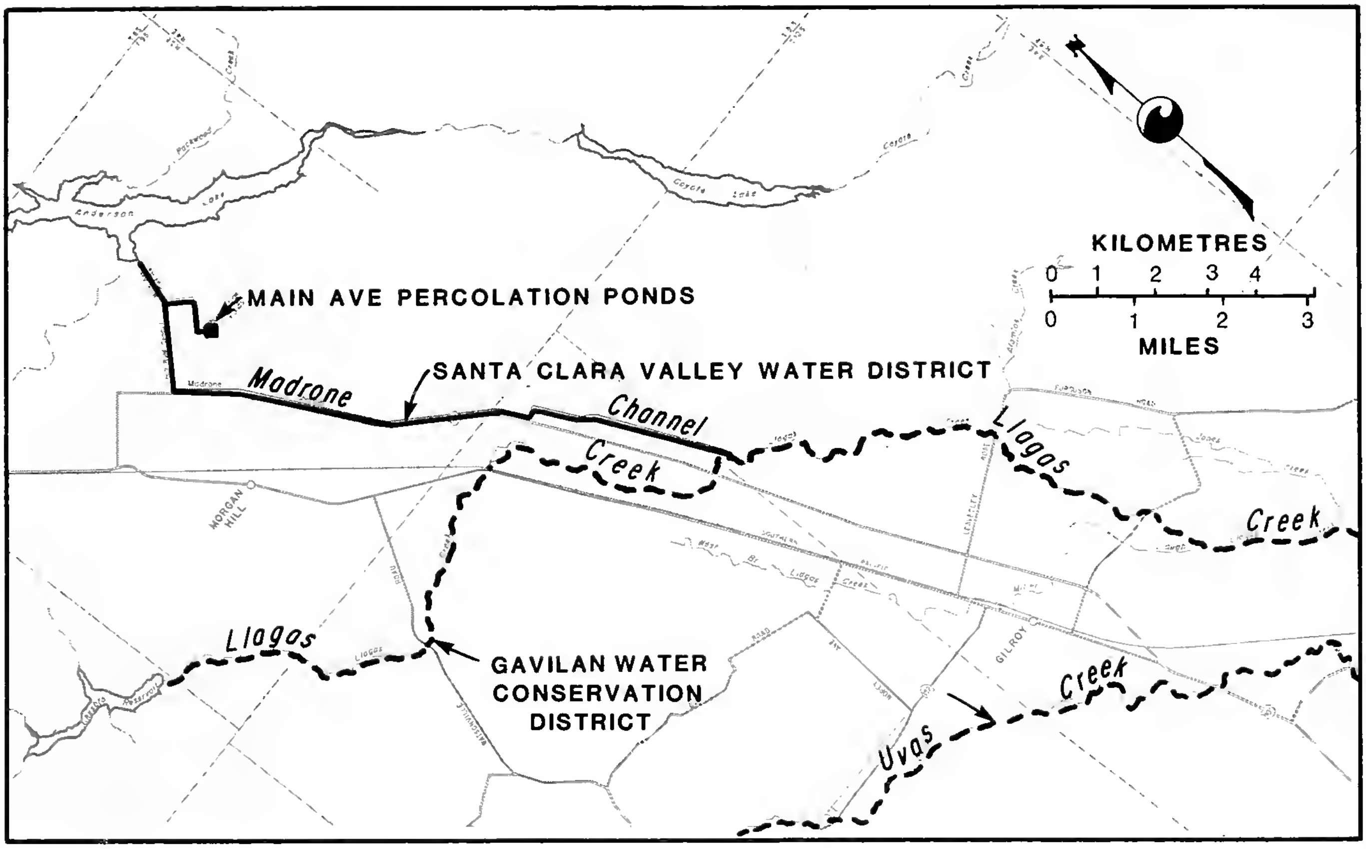


FIGURE 17.--Ground Water Recharge Facilities,
South Santa Clara Valley.

affords very little natural recharge because of underlying beds of nearly impermeable lake-bottom clays.

A number of ground water recharge facilities augment the natural recharge to Llagas Subbasin. Santa Clara Valley Water District operates such facilities at the Main Avenue Percolation Ponds and the Madrone Channel; a number of percolation ponds along Llagas and Uvas Creeks are operated by Gavilan Water Conservation District. The locations of these artificial recharge facilities are shown on Figure 17. Monthly releases to the Main Avenue ponds from 1959 to 1978 are shown on Figure 18.

Very little direct recharge is afforded to the Bolsa Subbasin from precipitation or streamflow due to the nearly impervious nature of the clayey materials. Most recharge occurs by way of underflow from such areas as the contiguous ground water terrain in the Lomerias Muertas to the west, or buried permeable materials which enter the subbasin from the south.

Ground Water Quality

A recent study of the South Santa Clara Valley area by Morgester and McCune (1980) indicated the following ground water quality characteristics:

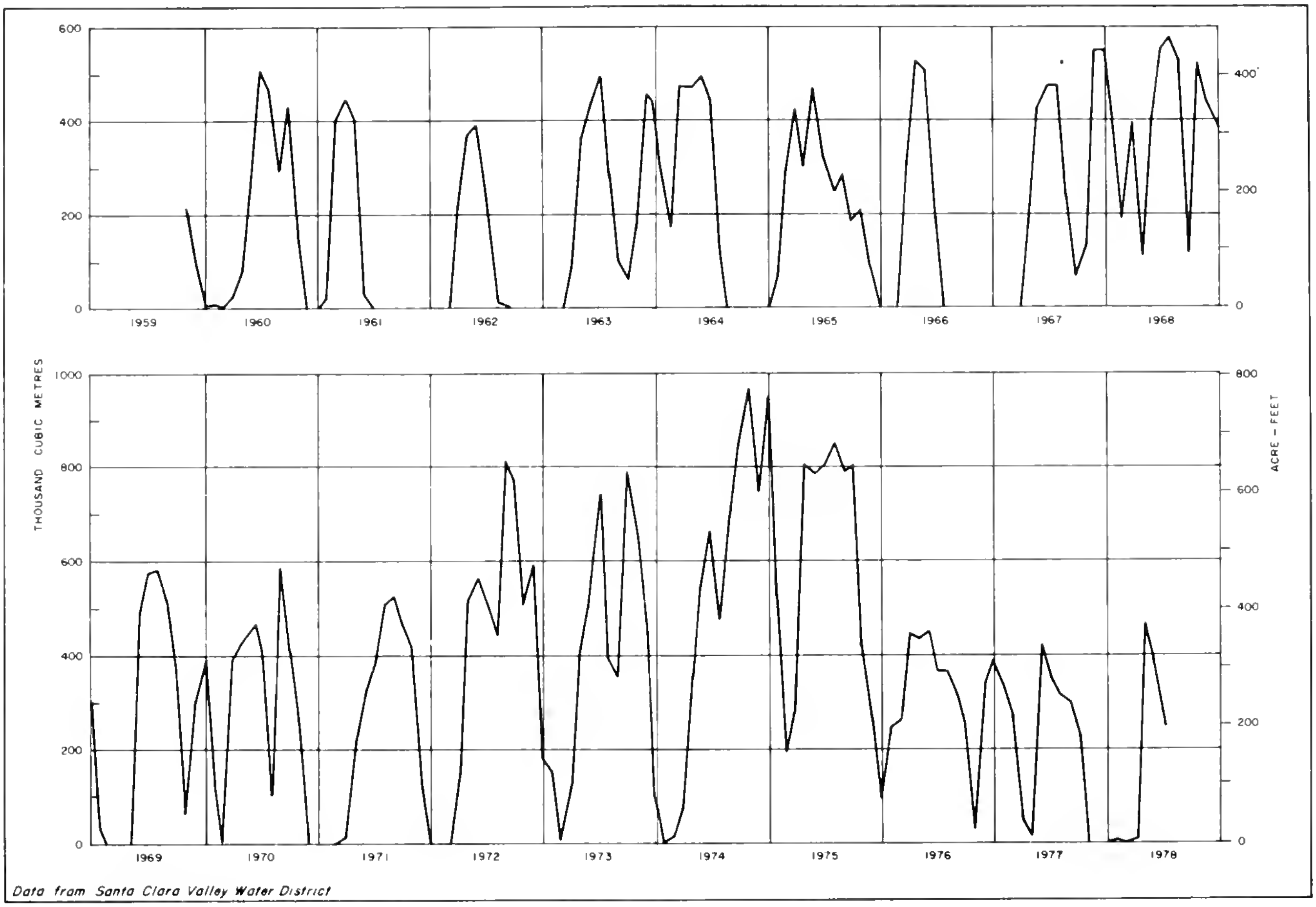


FIGURE 18.--Monthly Releases, by Calendar Year, to Main Avenue Percolation Ponds.

1. Ground water generally is hard, with samples from only a few wells showing hardness values of less than 200 milligrams per litre (mg/L).

2. Samples from only a very few wells had concentrations of boron in excess of 0.5 mg/L.

3. Samples from only 8 percent of the wells indicated an adjusted sodium adsorption ratio greater than 6.

4. Samples from 38 of the 198 wells sampled contained nitrate in excess of 45 mg/L.

5. Electrical conductivity (EC) values for 68 of the wells sampled were greater than 750 microsiemens per centimetre (uS), and six of these wells had EC values greater than 1 500 uS.

6. The majority of wells with potential boron, sodium, and salinity problems were in the southerly portion of the area, while most of the wells with high nitrate levels were in the central portion of the area.

CHAPTER IV. THE MATHEMATICAL MODEL

One of the objectives of the study of South Santa Clara Valley was the development of a digital computer model to be used as a tool in a water management program for this portion of Santa Clara County. The computer program used to perform the ground water simulation was originally developed in 1970; it has been used in a number of other ground water basins in this part of California, the most recent being North Santa Clara Valley.

The computer simulation of an aquifer system is based on a mathematical approximation of the basic ground water flow equation. The solution to this equation is obtained by applying a finite difference approach. To apply the finite difference approach, a nodal network, shown on Figure 19, is superimposed upon the ground water basin. The center of each element, or cell, of this network is called a node and is identified by a discrete number. The ground water model assumes that all physical and hydrologic characteristics of a particular cell are located at the node point. Ground water flow between adjacent cells is treated in the same manner as a spill from a reservoir. That is, once the head rises above some minimum level, ground water begins to spill into an adjacent cell. The quantity and velocity of flow are controlled by the transmissivity of each cell boundary.

The basic ground water flow equation in finite difference form is written for each node in the model. A large system of simultaneous equations is created having the hydraulic head for each node and flows through cell boundaries as unknowns. This system of equations is solved by an iterative procedure that is repeated until it has converged to a solution.

Input to the model is in the form of data which describe the physical conditions of the various nodes in the ground water basin. Nodal parameters, shown on Table 3, indicate for each node its surface area, surface and bedrock elevations, average specific yield, and elevation of the potentiometric surface for the initial model run. Connections between nodes are made by numbered branches, each of which has its own characteristics, such as width, length, the elevation below which transmissivity is assumed to be zero (the check elevation), and estimated transmissivity. These branch parameters are shown on Table 4.

The nodal parameters and configuration for the Coyote Subbasin portion of the model are identical with those previously established by the Santa Clara Valley Water District for their model for Coyote Subbasin; only the node and branch numbers have been changed.

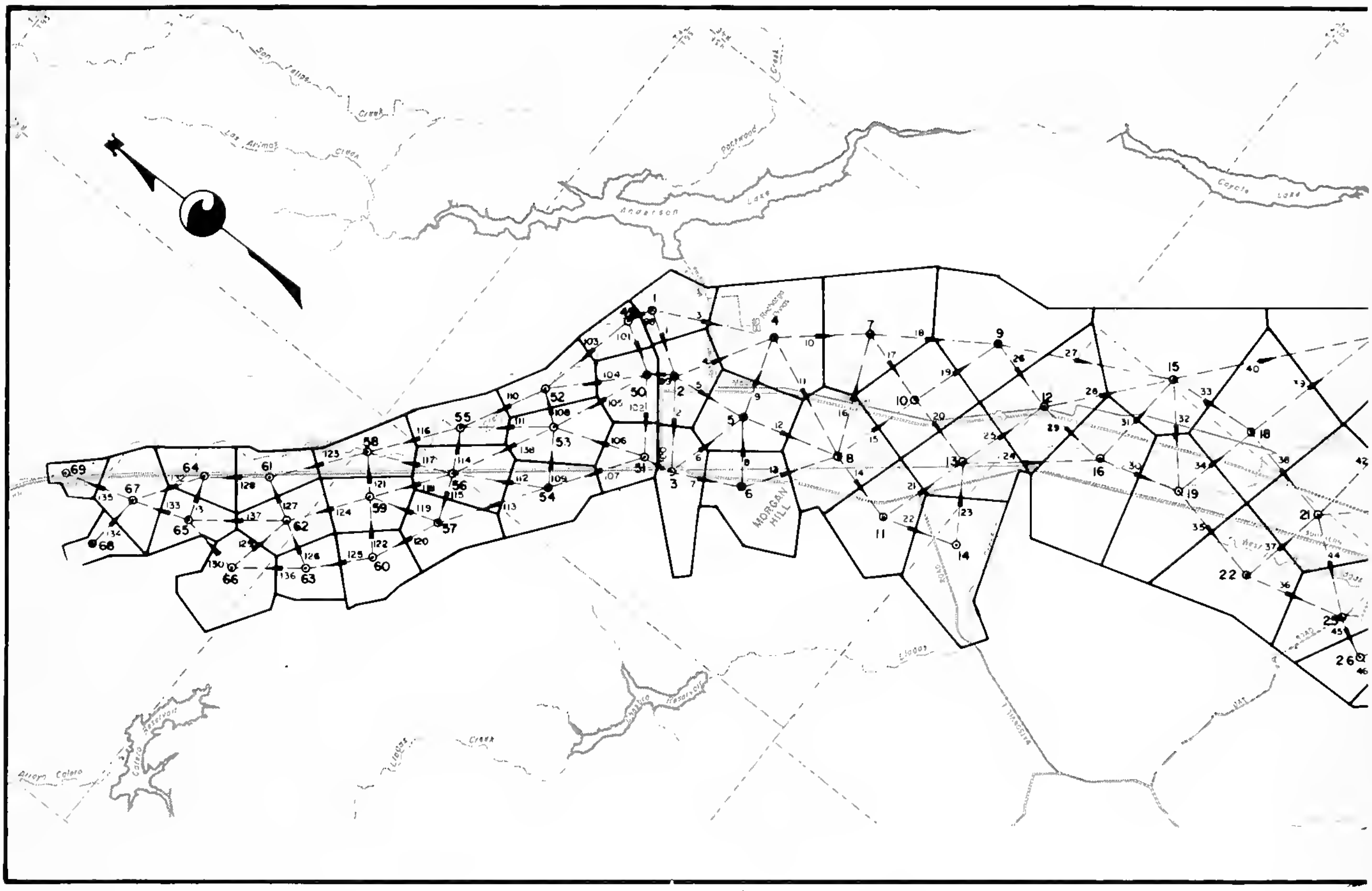
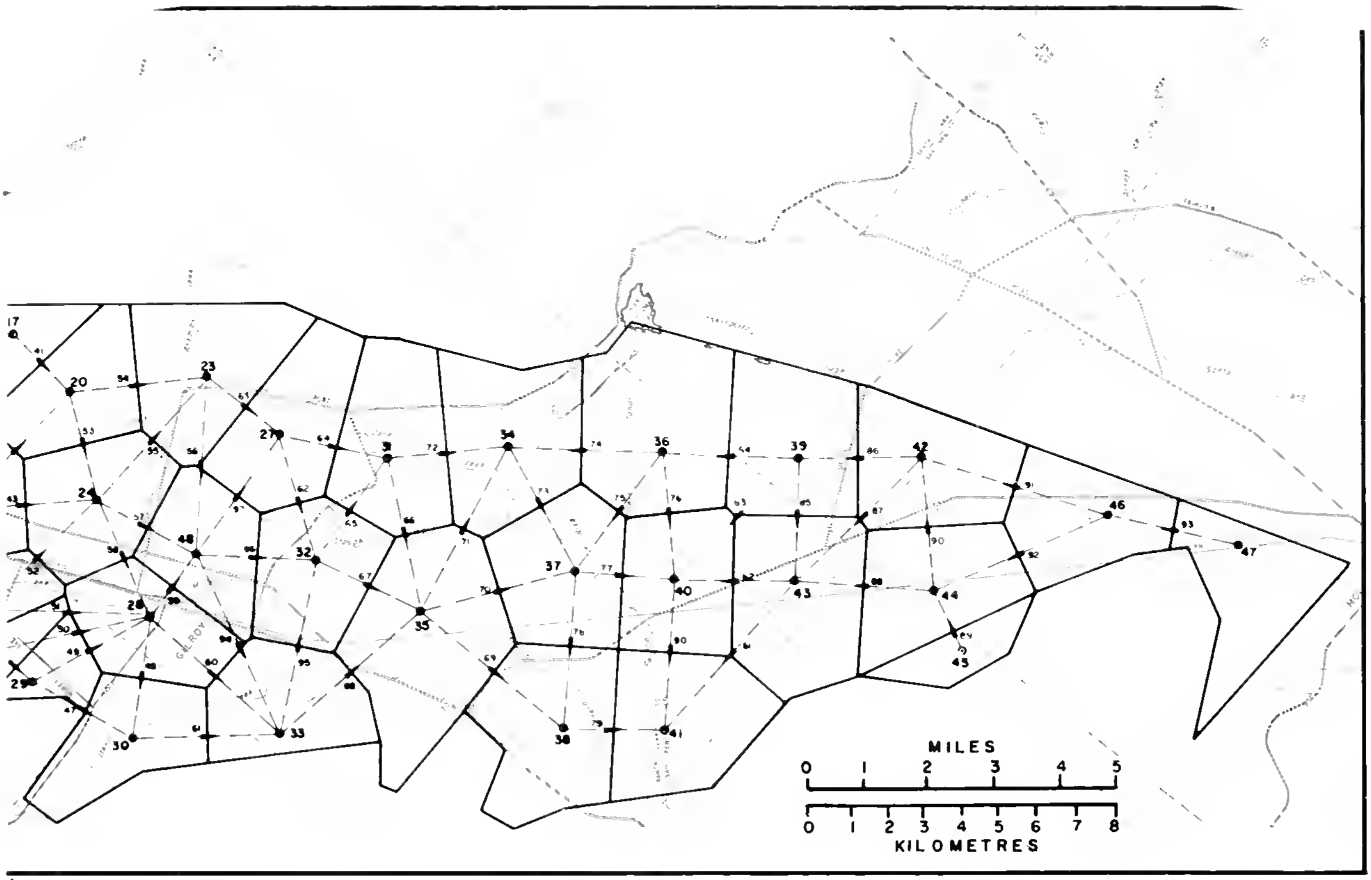


FIGURE 19.--Nodal Network, South

Description of the Model

The ground water model of South Santa Clara Valley is comprised of 69 cells (see Figure 19). Of these, cells 1 through 35, and cells 37, 38, and 48 are in Llagas Subbasin; cells 36, and 39 through 47 are in Bolsa Subbasin; and cells 49 through 69 are in Coyote Subbasin.

The entire boundary of the model network, with one exception, has been assumed to be a no-flow boundary. This exception is the northernmost side of cell 69, which is at Coyote Narrows and across which some ground water outflow from the model occurs. There may be other boundary segments across which some ground water may move; however, the quantity of flow is minor and, as far as the model is concerned, does not occur. Such points might be inflow at Llagas Creek (cell 14), inflow at Uvas Creek (cell 30), and outflow at the Pajaro River (cell 41). There also may be some inflow to the model from upland areas of the Santa Clara Formation, particularly to the east of the valley (cells 4, 7, 9, 15, 17, 20, 23, 27, 31, and 34), and from the Purisima Formation (cells 41, 43, 45, 46, and 47). Any inflow that would take place from those areas probably would affect only deeper wells and would have little if any effect on model operation.



Santa Clara Ground Water Model

Orientation of the nodal network was in part controlled by faults which transect the floor of South Santa Clara Valley and which may have some effect on ground water movement. One such fault is the Chesbro fault, which lies adjacent to the common boundary between cells 8 and 11, 10 and 13, and also 9 and 12. The unnamed fault which transects the valley near Rucker has been used as the common boundary between cells 17 and 20, 18 and 21, and also 19 and 22.

The ground water divide near Cochran Road has been defined in the model as the boundary between cells 1 and 49, 2 and 50, and 3 and 51. Ground water moves to the north and to the south from this divide; ground water normally will not move across this divide except in response to nearby pumping.

Because the southern portion of the South Santa Clara Valley area has been the site of a number of extensive lakes in the geologic past, widespread deposits of lake-bottom clays exist. To simulate the ground water confinement present in the area of lake-bottom sediments, cells 34 through 47 were defined as being entirely confined at the ground surface. The model treats the remaining cells as containing unconfined ground water.

Table 3. Nodal Parameters, South Santa Clara Valley Ground Water Model

Node Number	Surface Area		Surface Elevation		Bedrock Elevation		Average Specific Yield (Percent)	Initial Water Level Elevation	
	Acres	Hectares	Feet	Metres	Feet	Metres		Feet	Metres
1	363	147	400	122	0	0	5.00	329	100
2	428	173	380	116	80	24	9.00	288	88
3	514	208	360	110	150	46	5.50	323	98
4	1,061	429	380	116	-130	- 40	7.00	274	84
5	541	219	360	110	180	55	6.30	278	85
6	710	287	360	110	200	61	4.50	288	88
7	1,001	405	350	107	-150	- 46	9.00	262	80
8	805	326	340	104	-150	- 46	15.00	271	83
9	1,065	431	330	101	-100	- 30	3.60	235	72
10	685	277	330	101	-100	- 30	3.00	259	79
11	671	272	320	98	90	27	7.80	257	78
12	852	345	290	88	- 20	- 6	10.20	227	69
13	670	271	310	94	80	24	5.50	267	81
14	852	345	330	101	60	18	10.00	303	92
15	1,415	573	290	88	-120	- 37	6.50	217	66
16	1,143	463	290	88	10	3	6.10	234	71
17	1,093	442	270	82	- 90	- 27	5.00	195	59
18	1,208	489	260	79	-100	- 30	10.00	208	63
19	1,053	426	270	82	- 90	- 27	8.80	226	69
20	1,355	548	240	73	- 80	- 24	17.50	190	58
21	1,200	466	240	73	- 90	- 27	4.10	202	62
22	945	382	260	79	0	0	7.30	217	66
23	1,790	724	220	67	-100	- 30	7.90	170	52
24	1,460	591	210	64	-140	- 43	6.00	177	54
25	846	342	240	73	-100	- 30	6.40	196	60
26	457	185	240	73	20	6	7.00	180	55
27	1,621	656	190	58	-350	-167	5.80	174	53
28	1,401	567	210	64	-480	-146	8.00	170	52
29	482	195	240	73	0	0	7.70	193	59
30	1,373	556	230	70	20	6	7.80	189	58
31	1,676	678	180	55	-260	- 79	5.00	159	48
32	1,443	584	180	55	-170	- 52	6.70	151	46
33	1,459	590	210	64	- 70	- 21	6.40	163	50
34	1,927	780	180	55	-470	-143	6.80	159	48
35	2,555	1,034	180	55	-200	- 61	6.20	151	46
36	2,290	927	160	49	-170	- 52	4.00	110	34
37	1,620	656	160	49	- 80	- 24	8.50	138	42
38	1,907	772	190	58	-180	- 55	6.20	143	44
39	1,870	757	160	49	-550	-168	6.50	101	31
40	1,400	567	140	43	-490	-149	6.00	128	39
41	1,700	688	175	53	-550	-168	5.00	142	43
42	1,620	656	170	52	-340	-104	5.60	85	26
43	1,840	745	160	49	-300	- 91	15.00	113	34
44	1,380	558	180	55	-160	- 49	8.00	84	26
45	675	273	180	55	-550	-168	5.00	79	24
46	1,340	542	250	76	-700	-213	10.00	76	23
47	800	324	300	91	-350	-107	6.50	141	43
48	1,259	510	190	58	-190	- 58	11.00	173	53
49	225	91	395	120	200	61	9.90	294	90
50	365	148	380	116	-150	- 46	11.80	291	89
51	325	132	350	107	150	46	9.50	312	95
52	378	153	350	107	250	76	9.50	305	93
53	495	201	350	107	-100	- 30	11.80	294	90
54	546	221	330	101	0	0	11.80	303	92
55	379	153	320	98	50	15	11.80	288	88
56	483	195	320	98	-100	- 30	9.60	284	87
57	457	185	305	93	50	15	9.60	288	88
58	392	159	300	91	100	30	9.30	276	84
59	408	165	295	90	-100	- 30	9.70	272	83
60	424	172	285	87	175	53	9.00	270	82
61	337	136	280	85	- 50	- 15	9.90	253	77
62	414	168	270	82	- 50	- 15	12.00	256	78
63	321	130	270	82	150	46	8.90	266	81
64	343	139	270	82	- 25	- 8	7.00	248	76
65	309	125	250	76	0	0	7.00	240	73
66	606	245	255	78	50	15	7.00	260	79
67	451	183	250	76	0	0	7.00	240	73
68	174	70	250	76	50	15	7.00	241	73
69	166	67	240	73	100	30	9.90	230	70

Table 4. Branch Parameters, South Santa Clara Valley Ground Water Model

Branch Number	Connecting Nodes		Width		Length		Fault Check Elevation		Transmissivity*	
			Feet	Metres	Feet	Metres	Feet	Metres	A.F./year	dam^3/yr.
1	1	2	3,458	1,054	4,333	[illegible]	- 50	- 15	150.0	185.0
2	2	3	2,083	635	5,875	1,791	50	15	150.0	185.0
3	1	4	2,792	851	7,750	2,362	0	0	220.0	271.4
4	2	4	2,750	838	6,583	2,006	- 50	- 15	130.0	160.4
5	2	5	5,925	1,806	6,583	2,006	-100	- 30	130.0	160.4
6	3	5	1,708	521	5,625	1,715	50	15	130.0	160.4
7	3	6	3,458	1,054	4,375	1,334	200	61	70.0	86.3
8	6	5	4,583	1,397	4,333	1,321	50	15	130.0	160.4
9	5	4	5,292	1,613	5,208	1,587	- 50	- 15	180.0	222.0
10	4	7	6,750	2,057	5,917	1,804	- 50	- 15	200.0	246.7
11	4	8	1,583	483	8,333	2,540	- 50	- 15	130.0	160.4
12	5	8	3,417	1,042	6,333	1,930	-100	- 30	130.0	160.4
13	6	8	3,833	1,168	6,250	1,905	50	15	70.0	86.3
14	8	11	5,833	1,778	4,583	1,397	- 50	- 15	120.0	148.0
15	8	10	4,792	1,461	5,875	1,791	-100	- 30	150.0	185.0
16	8	7	2,083	635	7,792	2,375	-100	- 30	150.0	185.0
17	7	10	6,000	1,829	4,875	1,486	-100	- 30	150.0	185.0
18	7	9	4,417	1,346	7,833	2,387	-100	- 30	150.0	185.0
19	10	9	4,917	1,499	6,083	1,854	-100	- 30	150.0	185.0
20	10	13	6,000	1,829	4,875	1,496	- 50	- 15	120.0	148.0
21	11	13	2,833	863	5,917	1,804	0	0	120.0	148.0
22	11	14	5,167	1,575	4,875	1,496	- 50	- 15	100.0	123.4
23	14	13	5,000	1,524	5,083	1,549	50	15	100.0	123.4
24	13	16	1,000	305	8,417	2,566	- 50	- 15	100.0	123.4
25	13	12	5,250	1,600	5,958	1,816	- 50	- 15	150.0	185.0
26	9	12	8,542	2,604	4,792	1,461	-100	- 30	120.0	148.0
27	9	15	1,000	305	11,000	3,353	-100	- 30	100.0	123.4
28	12	15	4,583	1,397	8,083	2,464	-100	- 30	120.0	148.0
29	12	16	6,792	2,070	4,583	1,397	-100	- 30	100.0	123.4
30	16	19	8,700	2,652	5,250	1,600	-100	- 30	100.0	123.4
31	16	15	3,750	1,143	6,625	2,013	-100	- 30	100.0	123.4
32	15	19	2,083	635	6,875	2,096	-100	- 30	150.0	185.0
33	15	18	8,125	2,477	5,792	1,765	-100	- 30	210.0	259.0
34	19	18	5,583	1,702	5,792	1,765	-100	- 30	190.0	234.4
35	19	22	7,833	2,387	7,417	2,413	- 50	- 15	100.0	123.4
36	22	25	4,917	1,499	7,250	2,210	- 50	- 15	70.0	86.3
37	22	21	5,417	1,651	5,750	1,753	- 50	- 15	120.0	148.0
38	18	21	7,667	2,337	7,417	2,261	-100	- 30	150.0	185.0
39	18	17	7,500	2,286	9,583	2,921	-100	- 30	250.0	308.4
40	15	17	1,250	381	12,583	3,835	-100	- 30	100.0	123.4
41	17	20	10,417	3,175	5,125	1,562	-100	- 30	200.0	246.7
42	21	20	3,542	1,080	10,125	3,086	-100	- 30	150.0	185.0
43	21	24	5,708	1,740	8,750	2,667	-100	- 30	200.0	246.7
44	21	25	6,458	1,968	7,417	2,261	- 50	- 15	120.0	148.0
45	25	26	9,083	2,768	2,667	813	0	0	70.0	86.3
46	26	29	7,333	2,235	2,917	889	0	0	150.0	185.0
47	29	30	2,625	800	7,167	2,185	- 50	- 15	205.0	252.9
48	28	30	6,583	2,006	7,583	2,311	- 50	- 15	250.0	308.4
49	29	28	4,166	1,270	8,333	2,540	- 50	- 15	250.0	308.4
50	26	28	1,083	330	9,583	2,921	- 50	- 15	250.0	308.4
51	25	28	625	191	10,542	3,213	-100	- 30	250.0	308.4
52	25	24	3,125	953	10,000	3,048	-100	- 30	200.0	246.7
53	20	24	7,583	2,311	6,958	2,121	-100	- 30	250.0	308.4
54	20	23	7,833	2,387	8,542	2,604	-100	- 30	100.0	123.4
55	24	23	3,250	991	10,208	3,111	-100	- 30	200.0	246.7
56	23	48	1,125	343	11,000	3,353	-100	- 30	220.0	271.4
57	24	48	6,250	1,905	6,958	2,121	-100	- 30	350.0	431.7
58	24	28	4,500	1,372	8,000	2,438	-100	- 30	330.0	407.1
59	28	48	8,833	2,692	4,875	1,486	-100	- 30	320.0	394.7
60	28	33	3,750	1,143	10,833	3,302	0	0	250.0	308.4
61	30	33	4,583	1,397	9,083	2,768	50	15	200.0	246.7
62	27	32	4,166	1,270	8,167	2,489	-100	- 30	300.0	370.1
63	23	27	11,875	3,620	5,750	1,753	-100	- 30	150.0	185.0
64	27	31	10,208	3,111	6,833	2,083	-100	- 30	175.0	215.9
65	32	31	5,083	1,549	7,750	2,362	-100	- 30	300.0	370.1
66	31	35	3,750	1,143	9,792	2,985	-100	- 30	300.0	370.1
67	32	35	8,000	2,438	7,208	2,197	-100	- 30	420.0	518.1
68	33	35	6,146	1,873	11,667	3,556	-150	- 46	300.0	370.1
69	35	38	5,333	1,625	11,458	3,492	-150	- 46	480.0	592.1
70	35	37	6,750	2,057	9,917	3,023	-150	- 46	350.0	431.7

Table 4. Branch Parameters, South Santa Clara Valley Ground Water Model (Continued)

Branch Number	Connecting Nodes		Width		Length		Fault Check Elevation		Transmissivity*	
			Feet	Metres	Feet	Metres	Feet	Metres	A.F./year	dam^3/yr.
71	35	34	2,083	635	11,629	3,545	-150	- 46	300.0	370.1
72	31	34	10,917	3,328	7,500	2,286	-150	- 46	200.0	246.7
73	34	37	7,000	2,134	8,833	2,692	-200	- 61	260.0	320.7
74	36	34	7,833	2,387	9,583	2,921	-150	- 46	230.0	283.7
75	36	37	3,542	1,080	9,167	2,794	-150	- 46	270.0	333.0
76	36	40	6,167	1,880	7,917	2,413	-150	- 46	300.0	370.1
77	37	40	8,167	2,489	6,083	1,854	-200	- 61	350.0	431.7
78	37	38	6,333	1,930	9,792	2,985	-200	- 61	420.0	518.1
79	38	41	9,417	2,870	6,250	1,905	-250	- 76	600.0	740.1
80	40	41	7,000	2,134	9,375	2,858	-250	- 76	540.0	666.1
81	43	41	4,500	1,372	12,333	3,759	-300	- 91	600.0	740.1
82	43	40	8,750	2,667	7,500	2,286	-250	- 76	450.0	555.1
83	39	40	667	203	10,833	3,302	-200	- 61	350.0	431.7
84	39	36	9,792	2,985	8,458	2,578	-150	- 46	300.0	370.1
85	39	43	7,583	2,311	7,583	2,311	-200	- 61	450.0	555.1
86	42	39	8,250	2,515	7,583	2,311	-150	- 46	400.0	493.4
87	42	43	1,000	305	11,000	3,353	-250	- 76	400.0	493.4
88	44	43	9,083	2,768	8,667	2,642	-250	- 76	450.0	555.1
89	45	44	12,083	3,683	4,167	1,270	-200	- 61	300.0	370.1
90	44	42	8,333	2,540	8,333	2,540	-250	- 76	400.0	493.4
91	46	42	5,083	1,549	12,083	3,683	-250	- 76	600.0	740.1
92	46	44	4,708	1,435	11,792	3,594	-200	- 61	500.0	616.8
93	47	46	3,167	965	8,333	2,540	-200	- 61	720.0	888.1
94	48	33	500	152	12,292	3,747	0	0	300.0	370.1
95	33	32	5,167	1,575	11,042	3,366	0	0	300.0	370.1
96	48	32	7,667	2,337	7,417	2,261	-100	- 30	400.0	493.4
97	48	27	4,833	1,473	9,000	2,743	-100	- 30	280.0	345.4
98	1	49	3,250	991	1,667	508	100	30	10.0	12.3
99	2	50	4,833	1,473	1,667	508	-125	- 38	3.0	3.7
100	3	51	3,083	940	1,917	584	175	53	3.0	3.7
101	49	50	3,583	1,092	3,333	1,016	25	8	70.0	86.3
102	50	51	2,750	838	5,083	1,549	0	0	120.0	148.0
103	49	52	1,750	533	6,625	2,019	225	69	15.3	18.9
104	50	52	2,167	661	6,250	1,905	50	15	89.3	110.2
105	50	53	1,833	559	6,583	2,006	-125	- 38	113.9	140.5
106	51	53	2,917	889	5,875	1,791	25	- 8	123.3	152,1
107	51	54	1,750	533	6,167	1,880	75	23	25.5	31.5
108	53	52	5,417	1,651	2,333	711	75	23	127.5	157.3
109	54	53	4,917	1,499	3,792	1,156	- 50	- 15	158.1	195.0
110	52	55	1,916	584	5,750	1,753	150	- 46	25.5	31.5
111	53	55	1,667	508	5,750	1,753	- 25	- 8	127.5	157.3
112	54	56	3,500	1,067	5,917	1,804	- 50	- 15	146.2	180.3
113	54	57	1,500	457	7,083	2,159	25	8	12.8	15.8
114	56	55	5,500	1,676	2,833	863	- 25	- 8	148.8	183.5
115	56	57	5,333	1,625	3,125	953	- 25	- 8	63.8	78.7
116	55	58	2,000	610	5,875	1,791	75	23	43.4	53.5
117	56	58	1,833	559	5,417	1,651	0	0	198.1	244.4
118	56	59	750	229	5,333	1,625	-100	- 30	89.3	110.2
119	57	59	2,583	787	4,583	1,397	- 25	- 8	56.1	69.2
120	57	60	2,917	889	4,583	1,397	110	34	3.0	3.7
121	59	58	5,583	1,702	2,833	863	0	0	230.0	283.7
122	60	59	3,917	1,194	3,750	1,143	135	41	48.5	59.8
123	58	61	1,833	559	6,208	1,892	25	8	51.0	62.9
124	59	62	3,417	1,042	5,208	1,587	- 75	- 23	129.2	159.4
125	60	63	4,166	1,270	4,167	1,270	165	50	2.0	2.5
126	63	62	3,833	1,168	3,083	940	50	15	85.0	104.8
127	62	61	5,500	1,676	2,917	889	- 50	- 15	221.0	272.6
128	61	64	4,166	1,270	4,000	1,219	- 40	- 12	86.7	106.9
129	66	62	2,917	889	4,417	1,346	0	0	112.2	138.4
130	66	65	1,458	444	3,958	1,206	25	8	112.2	138.4
131	65	64	4,500	1,372	2,833	863	- 15	- 5	255.0	314.5
132	64	67	2,500	762	4,667	1,423	- 15	- 5	102.0	125.8
133	65	67	4,500	1,372	3,667	1,118	0	0	131.8	162.6
134	68	67	3,666	1,117	3,667	1,118	25	8	238.0	293.6
135	67	69	2,583	787	4,458	1,359	50	15	170.0	209.7
136	63	66	2,250	686	4,583	1,397	50	15	8.5	10.5
137	62	65	917	280	6,042	1,842	- 50	- 15	153.0	188.7
138	53	56	1,083	330	6,792	2,070	-150	- 46	140.3	173.1
139	69	70	2,400	732	14,620	4,456	75	23	200.0	246.7

Hydrologic Input

Construction of a ground water model requires hydrologic input, in the form of an inventory, for each cell of the model for each year of the selected study period. The inventory was determined by combining all inflow to the basin and all outflow from the basin, by year, thus obtaining the net annual flow. This flow was then apportioned to each node as shown on Table 5.

The reaction of a ground water basin under changing conditions depends not only upon the geologic framework of the basin, but also upon the basin's hydrologic balance for a particular time period. This balance takes into account precipitation, evaporation, evapotranspiration, recharge, discharge, and consumptive use. The analysis of a ground water basin is based on the amount of water in storage, which is reflected by ground water levels throughout the basin. When the change in the amount of ground water in storage from one point in time to another during a given study period matches the computed hydrologic balance of the basin for that same time period, the resulting inflows and outflows can be used as input to the mathematical model.

The current study has been based on an inventory of the following flows to and from the Santa Clara ground water basin:

Inflows

Deep Percolation
Stream Percolation
Pond Percolation (artificial recharge)
Subsurface Inflow

Outflows

Agricultural Pumpage
Urban Pumpage
Subsurface Outflow

In order to derive a hydrologic inventory, the following two criteria must be observed: 1) the inventory must result in a hydrologic balance for the entire basin, and 2) the inventory must determine the net flow for each individual node as representative of the hydrologic balance for that node.

The hydrologic balance resulting from the inventory reflects the theoretical change in the amount of ground water in storage. The accuracy of the inventory can be estimated by comparing the change in storage derived by this method to that calculated from changes in historic water levels.

Certain items in the ground water inventory were measured directly, a few were calculated, and some were measured for only a part of the study period and calculated for the remainder. Of

those items that were calculated, most were prepared on a water year basis (October 1 through September 30). The principal exception was ground water pumpage, which was prepared on a calendar year basis. However, because a calendar year and a water year both contain the same summer period, during which the greatest variation in pumpage occurs, the use of the calendar year for determining pumpage has only a minor effect on the calculations.

Net annual flows determined for the study period (1965-73) are shown on Table 5. These, coupled with the initial ground water elevations for each node, shown on Table 3, were used as hydrologic input to the model.

Precipitation

An isohyetal map showing the variation of mean annual precipitation in the study area is shown on Figure 20. The precipitation data and the isohyets were adapted from data provided by the Santa Clara Valley Water Distrct. Base stations used to develop the isohyetal map were selected based on the length and reliability of station records, representative geographic and topographic conditions in the area, and orographic storm pattern. A common 52-year span, 1919-1970, was used in the preparation of the isohyetal map.

The yearly amounts of rainfall at Gilroy and Morgan Hill stations, from 1948 through 1975, are shown on Figure 14. The accumulated percent deviation from the mean for Morgan Hill and Hollister stations is shown on Figure 21.

Tributary Runoff

Only a small portion of the drainage area tributary to South Santa Clara Valley is gaged. Runoff from the remaining area was estimated by developing runoff-precipitation relationships for the gaged areas and applying these relationships to the ungaged areas. The locations of tributary drainage areas are shown on Figure 22. Table 6 lists the tributary drainage areas and their estimated amounts of annual runoff for the years 1965 through 1973.

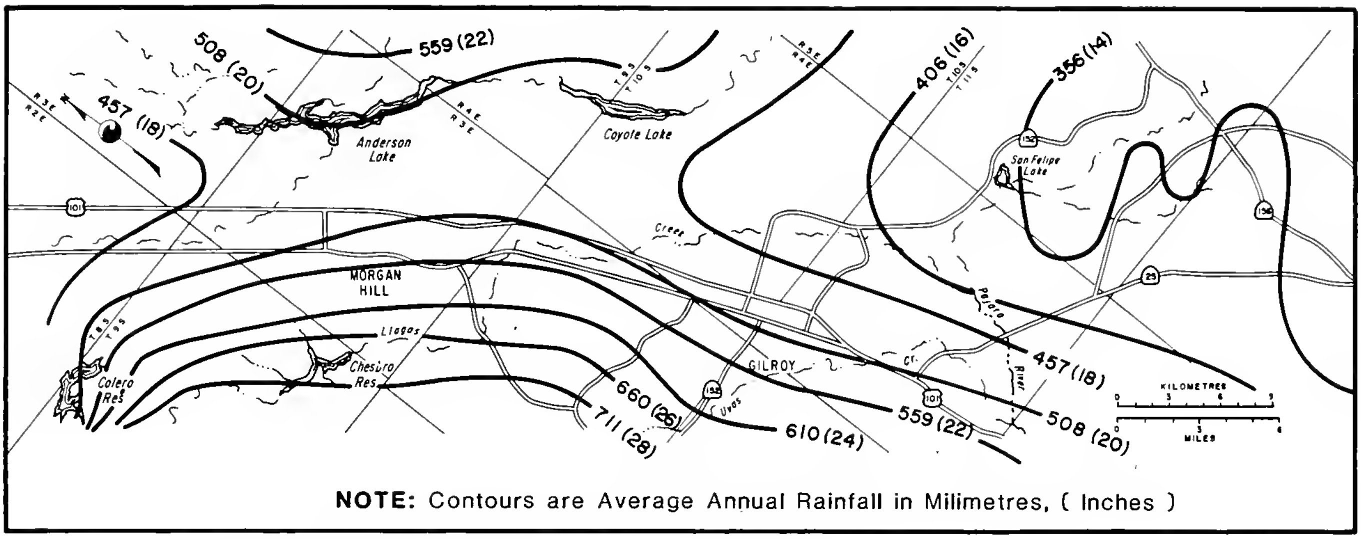
For developing correlation curves used in estimating tributary runoff, known seasonal runoff was plotted against seasonal precipitation. The straight line relationship between seasonal runoff and seasonal precipitation was used to determine the amount of precipitation that would be required to initiate runoff along ungaged streams.

Seasonal runoff from an ungaged area can be computed from the following formula when nearby runoff and precipitation data are available:

Table 5. Net Annual Flows, South Santa Clara Valley Ground Water Model

Node Number	Water Year 1964-1965	1965-1966	1966-1967	1967-1968	1968-1969	1969-1970	1970-1971	1971-1972	1972-1973
	(Acre-Feet)								
1	3,166	2,682	3,654	2,657	3,333	2,968	2,922	2,613	3,197
2	-540	-738	0	-849	-169	-574	-445	-577	-267
3	1,220	690	1,580	692	1,425	925	1,014	595	1,592
4	1,330	619	1,683	915	2,295	1,362	1,279	1,022	2,362
5	-452	-669	-252	-626	163	-309	-449	-597	-49
6	414	30	734	-5[illegible]	640	74	151	-178	663
7	-1,167	-1,486	-276	-1,553	38	-939	-959	-1,512	-150
8	-409	-746	115	-694	427	-360	-408	-635	285
9	-353	-1,079	176	-1,213	484	-716	-706	-,1389	75
10	-781	-1,171	-585	-1,102	51	-643	-772	-963	-85
11	545	99	982	32	999	345	375	-30	953
12	-301	-1,140	116	-1,106	47	-772	-616	-934	846
13	280	-751	737	-774	278	-466	-278	-776	1,137
14	8,775	4,659	9,747	4,086	4,636	3,697	5,881	3,872	11,447
15	-988	-1,899	-218	-1,878	411	-987	-982	-1,646	306
16	659	-749	1,279	-827	692	-391	-29	-827	1,936
17	-246	-999	189	-980	400	-539	-383	-874	450
18	150	-1,436	764	-1,556	48	-1,061	-512	-1,308	2,015
19	206	-1,117	985	-1,297	138	-886	-481	-1,444	1,450
20	263	-1,640	726	-1,959	-450	-1,580	-872	-2,004	1,704
21	-653	-1,605	-282	-1,521	147	-1,025	-915	-1,419	592
22	-682	-1,238	216	-1,354	311	-768	-792	-1,507	64
23	290	-1,591	1,041	-2,009	289	-1,345	-762	-2,156	1,462
24	-2,164	-2,704	-1,303	-2,880	-761	-2,035	-2,152	-2,852	-1,217
25	-385	-772	83	-816	465	-335	-387	-826	145
26	102	-233	433	-282	500	-25	-35	-369	340
27	-828	-2541	-181	-2,919	-1,169	-2,429	-1,789	-2,991	360
28	-222	-542	417	-606	822	181	-203	-556	370
29	94	-346	499	-375	563	-37	30	-293	590
30	6,280	2,458	8,623	3,059	5,147	3,454	4,280	404	8,896
31	2,598	1,058	3,341	-1,479	719	-558	172	121	3,277
32	-875	-1,994	-251	-2,331	-806	-1,770	-1,435	-2,126	106
33	1,746	-657	4,299	-571	3,700	-192	906	-1,944	2,774
34	2,284	-1,887	3,536	-2,610	-776	-2,294	-1,327	-3,511	3,315
35	304	-1,428	3,389	-3,038	3,528	-1,950	-673	-2,594	527
36	459	-1,692	1,390	-1,647	189	-1,300	-1,044	-2,065	1,565
37	1,465	-1,906	3,019	-2,330	-353	-2,050	-994	-2,709	2,929
38	-450	-2,151	2,325	-2,355	2,764	-2,016	-754	-3,021	-379
39	-2,091	-2,521	-1,666	-2,376	-1,191	-1,961	-2,183	-2,710	-1,974
40	-20	-1,152	918	-1,171	916	-871	-466	-1,485	36
41	947	-1,611	4,482	-1,838	4,101	-1,287	-339	-2,718	1,003
42	-1,610	-2,019	-1,204	-1,978	-588	-1,517	-1,730	-2,337	-1,431
43	-610	-1,252	-267	-1,175	486	-769	-1,125	-1,909	-836
44	-937	-1,396	-527	-1,395	109	-908	-1,174	-1,677	-847
45	227	-387	1,031	-450	1,650	343	23	-473	876
46	-2,059	-2,598	-1,510	-2,857	-1,278	-2,043	-2,192	-2,838	1,723
47	5,274	5,391	6,049	5,229	6,295	5,289	5,265	4,794	5,456
48	-1,171	-1,490	-512	-1,558	-214	-1,082	-1,154	-1,612	-542
49	2,380	1,709	2,444	1,847	2,482	2,414	2,182	2,039	2,347
50	-364	-532	-261	-615	-114	-447	-489	-606	-223
51	82	-120	299	-150	368	4	27	-163	321
52	1,245	280	1,311	442	1,374	1,195	893	641	1,148
53	-541	-721	-357	-750	-71	-463	-410	-501	-67
54	-401	-737	-3	-775	174	-429	-422	-718	115
55	1,220	286	1,311	459	1,414	1,232	899	637	1,115
56	-434	-694	-210	-830	27	-292	-387	-542	-143
57	-310	-694	110	-722	162	-386	-357	-693	187
58	1,089	182	1,209	333	1,275	1,064	790	556	1,102
59	-585	-749	-400	-821	-168	-562	-600	-800	-344
60	-267	-589	71	-648	136	-372	-411	-811	0
61	895	73	1,003	195	1,089	901	614	364	863
62	-548	-697	-366	-765	-168	-528	-563	-743	-338
63	127	-448	8	-468	95	-255	-264	-474	51
64	1,285	-23	857	82	924	780	480	213	657
65	-420	-511	-258	-541	-151	-390	-418	-537	-244
66	-51	-446	230	-483	330	-255	-223	-536	219
67	177	-412	252	-374	485	209	47	-177	288
68	66	-204	231	-214	99	-138	-32	-170	296
69	833	276	860	439	878	874	674	550	747
TOTAL	24,562	-40,418	67,865	-48,077	52,091	-18,358	-7,189	-53,442	63,698

Node Number	Water Year 1964-1965	1965-1966	1966-1967	1967-1968	1968-1969	1969-1970	1970-1971	1971-1972	1972-1973
	(Cubic Dekametres)								
1	3,905	3,308	4,507	3,277	4,111	3,661	3,604	3,223	3,943
2	-666	-910	0	1,047	-208	-708	-549	-712	-329
3	1,505	851	1,949	854	1,758	1,141	1,251	734	1,964
4	1,641	764	2,076	1,129	2,831	1,680	1,578	1,261	2,914
5	-558	-825	-311	-772	201	-381	-554	-736	-60
6	511	37	905	-65	789	91	-186	-220	818
7	-1,439	-1,833	-340	-1,916	47	-1,158	-1,183	-1,865	-185
8	-505	-920	142	-856	527	-444	-503	-783	352
9	-435	-1,331	217	-1,496	597	-883	-871	-1,713	93
10	-963	-1,444	-722	-1,359	63	-793	-952	-1,188	-105
11	672	122	1,211	39	1,232	426	463	-37	1,176
12	-371	-1,406	143	-1,364	58	-952	-760	-1,152	1,044
13	345	-926	909	-955	343	-575	-343	-957	1,402
14	10,824	5,747	12,023	5,040	5,719	4,560	7,254	4,776	14,120
15	1,219	-2,342	-269	-2,317	507	-1,217	-1,211	-2,030	377
16	813	-924	1,578	-1,020	854	-482	-36	-1,020	2,388
17	-303	-1,232	233	-1,209	493	-665	-472	-1,078	555
18	185	-1,771	942	-1,919	59	-1,309	-632	-1,613	2,486
19	254	-1,378	1,215	-1,600	170	-1,093	-593	-1,781	1,789
20	324	-2,023	896	-2,416	-555	-1,949	-1,076	-2,472	2,102
21	-805	-1,980	-348	-1,876	181	-1,264	-1,129	-1,750	730
22	-841	-1,527	266	-1,670	384	-947	-977	-1,859	79
23	358	-1,962	1,284	-2,478	356	-1,659	-940	-2,659	1,803
24	-2,669	-3,335	-1,607	-3,552	-939	-2,510	-2,654	-3,518	-1,501
25	-475	-952	102	-1,007	574	-413	-477	-1,019	179
26	126	-287	534	-348	617	-31	-43	-455	419
27	-1-021	-3,134	-223	-3,601	-1,442	-2,296	-2,207	-3,689	444
28	-274	-669	514	-748	1,014	-223	-250	-686	456
29	116	-427	616	-463	694	-46	37	-361	728
30	7,746	3,032	10,636	3,773	6,349	4,261	5,279	498	10,973
31	3,205	1,305	4,121	-1,324	887	-688	212	149	4,042
32	-1,079	2,460	-310	-2,875	-944	-2,183	-1,770	-2,622	131
33	2,154	-810	5,303	-704	4,564	-237	1,118	-2,398	3,422
34	2,817	-2,328	4,362	-3,219	-957	-2,830	-1,637	-4,331	4,089
35	375	-1,761	4,180	-3,747	4,352	-2,405	-830	-3,200	650
36	566	-2,087	1,715	-2,032	223	-1,604	-1,288	-2,547	1,930
37	1,807	-2,351	3,724	-2,874	-435	-2,529	-1,226	-3,342	3,613
38	-555	-2,653	2,868	-2,905	3,409	-2,487	-930	-3,726	-467
39	-2,579	-3,110	-2,055	-2,931	-1,469	-2,419	-2,693	-3,343	-2,435
40	-25	-1,421	1,132	-1,444	1,130	-1,074	-575	-1,832	44
41	1,168	-1,987	5,529	-2,267	5,059	-1,588	-418	-3,353	1,237
42	-1,986	-2,490	-1,485	-2,440	-725	-1,871	-2,134	-2,883	-1,765
43	-752	-1,544	-329	-1,449	599	-949	-1,388	-2,355	-1,031
44	-1,156	-1,722	-650	-1,721	134	-1,120	-1,448	-2,069	-1,045
45	280	-477	1,272	-555	2,035	423	28	-583	1,081
46	-2,540	-3,205	-1,863	-3,524	-1,576	-2,520	-2,704	-3,501	-2,125
47	6,505	6,650	7,461	6,450	7,765	6,524	6,494	5,913	6,730
48	-1,444	-1,838	-632	-1,922	-264	-1,335	-1,423	-1,988	-669
49	2,936	2,108	3,015	2,278	3,062	2,978	2,691	2,515	2,895
50	-449	-656	-322	-759	-141	-551	-603	-748	-275
51	101	-148	369	-185	454	5	33	-201	396
52	1,536	345	1,617	545	1,695	1,474	1,102	791	1,416
53	-667	-889	-440	-925	-88	-571	-506	-618	-83
54	-495	-909	-4	-956	215	-529	-521	-886	142
55	1,505	353	1,617	566	1,744	1,520	1,109	-786	1,375
56	-535	-856	-259	-1,024	33	-360	-477	-669	-176
57	-382	-856	136	-891	200	-476	-440	-855	231
58	1,343	224	1,491	411	1,573	1,312	974	686	1,359
59	-722	-924	-493	-1,013	-207	-693	-740	-987	-424
60	-329	-727	88	-799	168	-459	-507	-1,000	0
61	1,104	90	1,237	241	1,343	1,111	757	499	1,065
62	-676	-860	-451	-944	-207	-651	-694	-916	-417
63	157	-553	10	-577	117	-315	-326	-585	63
64	1,585	-28	1,057	101	1,140	962	592	263	810
65	-518	-630	-318	-667	-186	-481	-516	-662	-301
66	-63	-550	284	-596	407	-315	-275	-661	270
67	218	-508	311	-461	598	258	58	-218	355
68	81	-252	285	-264	122	-170	-39	-210	365
69	1,028	340	1,061	542	1,083	1,078	831	678	921
TOTAL	30,300	-49,852	-83,712	-59,302	64,256	-22,643	-8,869	-65,920	78,573



NOTE: Contours are Average Annual Rainfall in Milimetres, (Inches)

FIGURE 20.--Isohyetal Contours, South Santa Clara Valley.

$$R_u = R_g \ (P_u/P_g)(Au/Ag),$$

where R_u = Seasonal runoff from ungaged area

R_g = Seasonal runoff from representative gaged area

P_u = Seasonal precipitation on the ungaged area

P_g = Seasonal precipitation on the representative gaged area, and

Au = Area of ungaged area

Ag = Area of gaged area.

Similarly, the annual basin precipitation can be estimated by the following formula, if mean seasonal precipitation data are available:

$$P_a = (P_i \cdot P'_a)/(P'_a \cdot P'_i)$$

where P_a = Annual basin precipitation

P'_a = Mean seasonal basin precipitation, estimated from isohyetal map

P_i = Seasonal precipitation at nearby index station, and

P'_i = Mean seasonal precipitation at nearby index station.

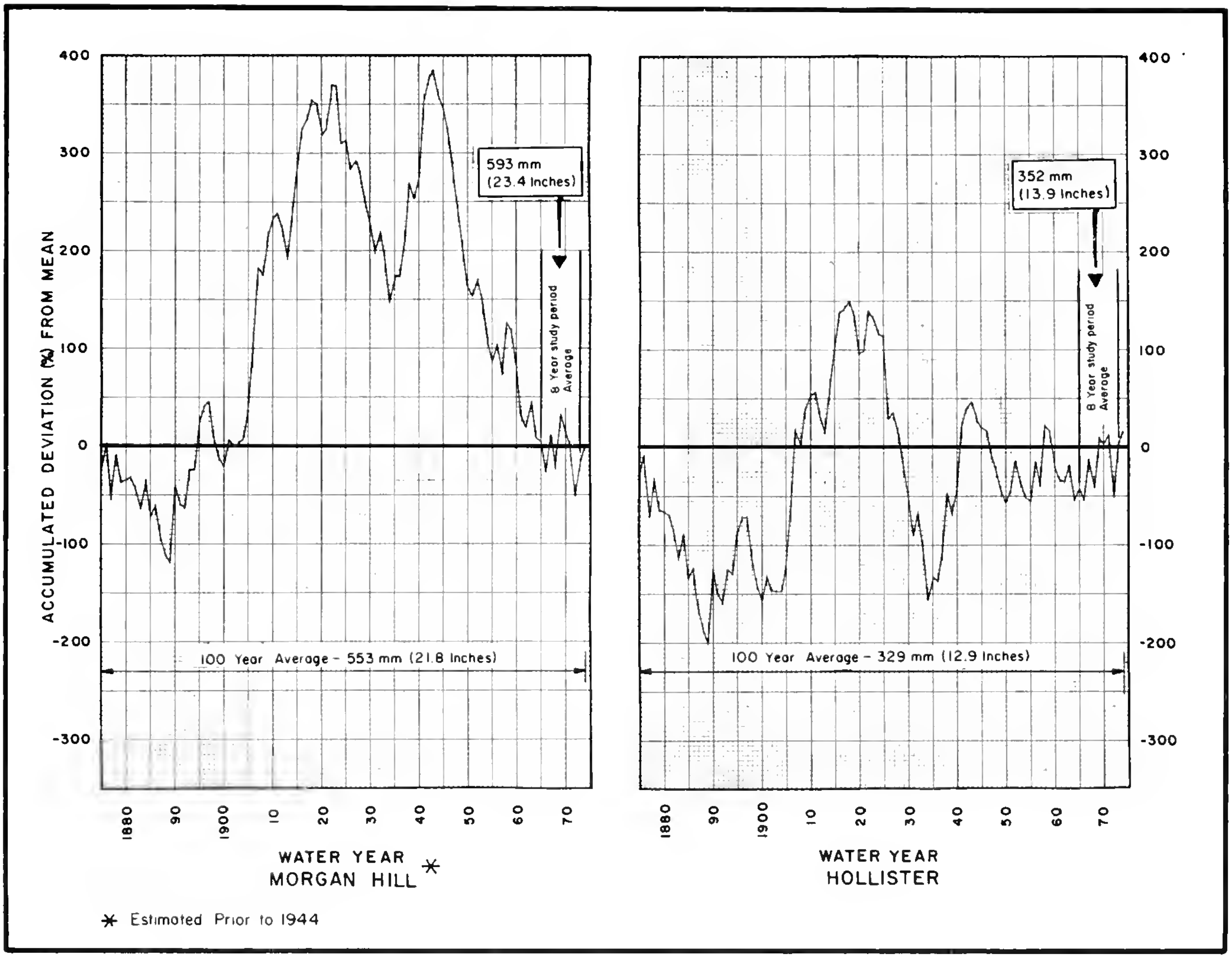


FIGURE 21.--Accumulated Deviation from Mean Precipitation at Two Stations, South Santa Clara Valley.

Artificial Recharge

Artificial recharge is the practice of deliberately ponding water for direct infiltration to the ground water body. Artificial recharge in South Santa Clara Valley is composed principally of waters released from Anderson Reservoir by Santa Clara Valley Water District for infiltration either at the Main Avenue Percolation Ponds or along the Madrone Channel (see Figure 17). This operation is the only well defined artificial recharge practiced in South Santa Clara Valley.

Gavilan Water Conservation District (GWCD) practices ground water recharge using waters released from Uvas and Chesbro Reservoirs. The GWCD stores the water during the wet season of the year and releases it during the dry season, thus affording a greater opportunity for the waters to infiltrate the channels of Uvas and Llagas Creeks.

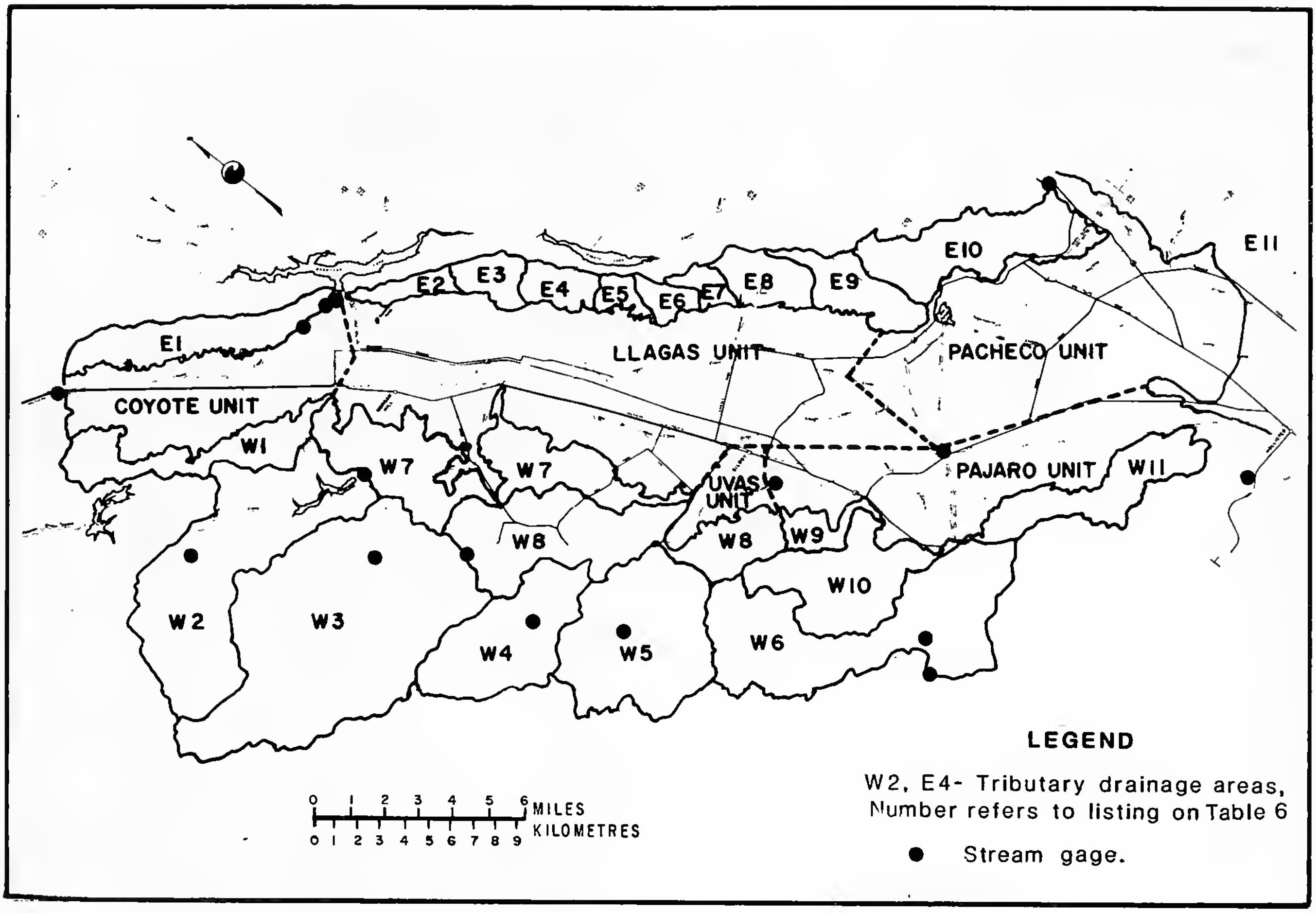


FIGURE 22.--Stream Percolation Units and Tributary Drainage Areas, South Santa Clara Valley.

Stream Infiltration

Stream infiltration in the South Santa Clara Valley was determined by the use of the gaging stations within the area. The basin was subdivided into stream infiltration units that reflected the positions of the gaging stations. These units are: Coyote Unit, Uvas Unit, Llagas Unit, Pajaro Unit, and Pacheco Unit.

The stream infiltration values derived for these units were divided into subunits coincident with the nodal areas of the ground water model (Table 7). The difference of flow between the inflow gaging station and the outflow gaging station of a stream infiltration unit is assumed to be the total stream infiltration for that unit. Stream infiltration values are applied to each node of the ground water model, based on the ratio of streambed distance within each node to total distance within the unit.

Coyote Unit

The Coyote Unit includes all of the Coyote Subbasin. There are two main channels in this unit, Coyote Creek and Coyote Canal,

Table 6. Tributary Runoff, South Santa Clara Valley

Drainage Area*	Area (mi2)	Water Year 1964-1965	1965-1966	1966-1967	1967-1968	1968-1969	1969-1970	1970-1971	1971-1972	1972-1973	Total
						(1,000 Acre-Feet)					
E-1	6.8	0	0	1.42	0	6.02	0.54	0.58	0.08	1.82	10.46
E-2	1.3	0.35	0.14	0.38	0.14	0.62	0.21	0.21	0.04	0.59	2.68
E-3	2.0	0.55	0.22	0.60	0.22	0.98	0.33	0.33	0.04	0.98	4.25
E-4	2.4	0.65	0.13	1.54	0	1.66	0.34	0.32	0	1.15	5.79
E-5	1.1	0.30	0.06	0.71	0	0.76	0.16	0.15	0	0.53	2.67
E-6	1.8	0.50	0.10	1.18	0	1.27	0.26	0.24	0	0.88	4.43
E-7	1.3	0.32	0.12	0.72	0	0.88	0.35	0.18	0	0.55	3.12
E-8	3.7	0.94	0.35	2.05	0	2.48	1.00	0.51	0	1.56	8.89
E-9	3.3	0.85	0.32	1.87	0	2.26	0.91	0.46	0	1.42	8.09
E-10	9.0	1.02	0.44	2.54	0.03	3.90	1.38	0.57	0.07	2.11	12.06
E-11	142.0	3.60	1.80	18.20	0	29.10	1.80	2.70	0	29.10	86.30
W-1	5.8	1.54	1.35	4.14	1.89	9.52	0.85	0.92	0.13	2.87	23.21
W-2	19.6	8.88	5.05	20.98	8.35	24.05	9.20	5.65	4.24	21.47	107.87
W-3	30.4	27.81	8.55	54.99	10.18	50.43	30.04	16.24	5.73	43.72	247.74
W-4	12.0	12.52	2.31	18.45	2.44	13.94	10.70	3.62	1.01	12.01	77.03
W-5	13.4	9.54	1.95	15.53	2.21	13.63	8.95	3.45	1.06	11.54	67.86
W-6	9.0	8.53	1.52	12.40	1.73	11.16	6.94	2.31	0.65	8.52	53.76
W-7	13.6	9.14	2.13	16.15	2.37	13.94	8.68	4.00	1.21	11.79	69.42
W-8	16.9	8.56	1.99	15.14	2.22	13.06	8.13	3.73	1.19	11.84	65.86
W-9	2.0	0.84	0.14	1.21	0.16	1.09	0.77	0.22	0.06	0.83	5.32
W-10	9.8	4.48	0.74	6.49	0.87	5.85	4.13	1.19	0.34	4.42	28.51
W-11	6.4	1.04	0.44	2.51	0.04	3.96	1.40	0.58	0.06	2.14	12.17

*Drainage Area**	*Area (km2)*	*Water Year 1964-1965*	*1965 1966*	*1966-1967*	*1967-1968*	*1968-1969*	*1969-1970*	*1970-1971*	*1971-1972*	*1972-1973*	*Total*
						(1,000 Cubic Dekametres)					
E-1	17.6	0	0	1.75	0	7.40	0.66	0.71	0.10	2.24	12.87
E-2	3.4	0.43	0.17	0.47	0.17	0.76	0.26	0.26	0.05	0.73	3.30
E-3	5.2	0.68	0.27	0.74	0.27	1.21	0.41	0.41	0.05	1.21	5.23
E-4	6.2	0.80	0.16	1.89	0	2.04	0.42	0.39	0	1.41	7.12
E-5	2.8	0.37	0.07	0.87	0	0.93	0.20	0.18	0	0.65	3.28
E-6	4.7	0.62	0.12	1.45	0	1.56	0.32	0.30	0	1.08	5.45
E-7	3.4	0.39	0.15	0.89	0	1.08	0.43	0.22	0	0.68	3.84
E-8	9.6	1.16	0.43	2.52	0	3.05	1.23	0.63	0	1.92	10.93
E-9	8.5	1.05	0.39	2.30	0	2.78	1.12	0.57	0	1.75	9.95
E-10	23.3	1.25	0.54	3.12	0.04	4.80	1.70	0.70	0.09	2.60	14.83
E-11	367.8	4.43	2.21	22.39	0	35.79	2.21	3.32	0	35.79	106.15
W-1	15.0	1.89	1.66	5.09	2.32	11.71	1.05	1.13	0.16	3.53	28.55
W-2	50.8	10.95	6.21	25.81	10.27	29.58	11.32	6.95	5.22	26.41	132.68
W-3	78.7	34.21	10.52	67.64	12.52	62.03	36.95	19.98	7.11	53.78	304.72
W-4	31.1	15.40	2.84	22.69	3.00	17.15	13.16	4.45	1.24	14.77	94.71
W-5	34.7	11.73	2.40	19.10	2.72	16.76	11.01	4.24	1.30	14.19	83.47
W-6	23.3	10.49	1.87	15.25	2.13	13.73	8.54	2.81	0.80	10.48	66.12
W-7	35.2	11.24	2.62	19.88	2.92	17.15	10.63	2.84	1.49	14.50	85.39
W-8	43.8	10.53	2.45	18.62	2.73	16.06	10.00	4.59	1.46	14.56	81.01
W-9	5.2	1.03	0.17	1.49	0.20	1.34	0.95	0.27	0.07	1.02	6.54
W-10	25.4	5.51	0.91	7.98	1.07	7.20	5.08	1.46	0.42	5.44	35.07
W-11	16.6	1.28	0.54	3.09	0.05	4.87	1.72	0.71	0.07	2.63	14.97

*See Figure 24 for location of tributary drainage areas.

Data for areas E-1 through E-9 from Santa Clara Valley Water District.

both of which flow north from Anderson Reservoir. Inflow into the Coyote Unit is by way of runoff from eastern and western slopes (tributary areas E-1 and W-1), as well as flow from Anderson Reservoir through Coyote Creek and Coyote Canal.

With the exception of 1969, the flow in Coyote Creek was determined from the gaging station just below Anderson Dam. Because of spill from Anderson Reservoir in 1969, the gaging station at Coyote Creek near Madrone was used for that year. The flow in Coyote Canal initially was determined from data from the gaging station at Metcalf Road. These data were modified to include leakage from Coyote Canal, estimated by SCVWD, and estimates of inflow from the east and west slopes.

Outflow from the Coyote Unit is along Coyote Creek, at Metcalf Road, and along the Coyote Canal, at the Diversion Dam. Estimated stream percolation for the Coyote Unit ranges from about 5 000 to 12 000 cubic dekametres (4,100 to 9,800 acre-feet) annually.

Uvas Unit

The Uvas Unit includes the drainage area of Uvas Creek from the western slopes to Gilroy. The gaged inflow to the unit from the western slopes was based on the three following gaging stations: Bodfish Creek near Gilroy (U. S. Geological Survey), Little Arthur Creek at Redwood Retreat Road (SCVWD), and Uvas Creek above Uvas Reservoir (USGS).

Evaporation from Uvas Reservoir was estimated from evaporation data and coefficients provided by the Santa Clara Valley Water District. Uvas Creek water exported to the Llagas Creek watershed was deleted from the total. Outflow from the Uvas Unit was by way of Uvas Creek at the USGS gaging station at Thomas Road. Except for 1972, when percolation was zero, stream percolation has ranged from about 11 200 to 32 200 dam^3 (9,100 to 26,100 acre-feet annually.

Llagas Unit

The Llagas Unit encompasses the drainage area of Llagas Creek from Cochran Road south to the Pajaro River. Inflow to the Llagas Unit includes Llagas Creek, runoff from the eastern slopes southerly from Anderson Reservoir, runoff from the western slopes from Cochran Road to Gilroy, and water imported from Uvas Creek.

Inflow from Llagas Creek was based on flows at the gaging station just below Chesbro Reservoir. These flows were taken from USGS records for the study period except for 1972 and 1973, which were derived from SCVWD records. Estimates of inflows from eastern slopes were from data provided by SCVWD. The stream percolation ranges from 3 800 to 46 700 dam^3 (3,100 to 37,900 acre-feet) annually.

Table 7. Stream Infiltration, South Santa Clara Valley

Node Number	Water Year 1964-1965	1965-1966	1966-1967	1967-1968	1968-1969	1969-1970	1970-1971	1971-1972	1972-1973	Water Year 1964-1965	1965-1966	1966-1967	1967-1968	1968-1969	1969-1970	1970-1971	1971-1972	1972-1973
	(Acre-Feet)									*(Cubic Dekametres)*								
COYOTE UNIT																		
1	0.27	0.14	0.25	0.19	0.27	0.32	0.23	0.23	0.20	0.33	0.17	0.31	0.23	0.33	0.39	0.28	0.28	0.24
49	0.92	0.46	0.83	0.62	0.90	1.08	0.79	0.78	0.68	1.13	0.57	1.02	0.76	1.11	1.33	0.97	0.96	0.84
52	1.21	0.60	1.08	0.81	1.17	1.41	1.03	1.02	0.88	1.49	0.74	1.33	1.00	1.44	1.73	1.27	1.25	1.08
55	1.21	0.60	1.08	0.81	1.17	1.41	1.03	1.02	0.88	1.49	0.74	1.33	1.00	1.44	1.73	1.27	1.25	1.08
56	0.18	0.09	0.17	0.12	0.18	0.22	0.16	0.16	0.13	0.22	0.11	0.21	0.15	0.22	0.27	0.20	0.20	0.16
58	1.11	0.55	0.99	0.75	1.08	1.30	0.94	0.93	0.81	1.37	0.68	1.22	0.92	1.33	1.60	1.16	1.14	1.00
61	1.02	0.51	0.91	0.68	0.99	1.19	0.86	0.86	0.74	1.25	0.63	1.12	0.84	1.22	1.46	1.06	1.06	0.91
64	1.02	0.51	0.91	0.68	0.99	1.19	0.86	0.86	0.74	1.25	0.63	1.12	0.84	1.22	1.46	1.06	1.06	0.91
67	0.64	0.32	0.58	0.43	0.63	0.75	0.54	0.54	0.47	0.79	0.39	0.71	0.53	0.77	0.92	0.66	0.66	0.58
69	0.74	0.36	0.67	0.50	0.72	0.87	0.63	0.62	0.54	0.91	0.44	0.82	0.62	0.89	1.07	0.77	0.76	0.66
TOTAL	8.32	4.14	7.47	5.59	8.10	9.74	7.07	7.02	6.07	10.23	5.10	9.19	6.89	9.97	11.96	8.70	8.62	7.46
LLAGAS UNIT																		
4	0.50	0.40	0.40	0.80	0.70	0.70	0.60	0.80	0.90	0.62	0.49	0.49	0.97	0.86	0.86	0.74	0.97	1.11
5	0.10	0.10	0.10	0.20	0.20	0.20	0.10	0.20	0.20	0.12	0.12	0.12	0.25	0.25	0.25	0.12	0.25	0.25
8	0.10	0.10	0.10	0.20	0.10	0.10	0.10	0.20	0.20	0.12	0.12	0.12	0.25	0.12	0.12	0.12	0.25	0.25
10	0.20	0.10	0.10	0.30	0.30	0.30	0.20	0.30	0.40	0.25	0.12	0.12	0.37	0.37	0.37	0.25	0.37	0.49
12	0.87	0.39	0.90	0.52	0.30	0.30	0.49	0.48	1.34	1.07	0.48	1.11	0.64	0.37	0.37	0.60	0.59	1.65
13	0.86	0.22	0.80	0.24	0.10	0.10	0.33	0.19	1.18	1.06	0.27	0.98	0.30	0.12	0.12	0.41	0.23	1.46
14	4.78	1.35	5.00	0.85	0	0	2.09	0.59	6.74	5.68	1.66	6.15	1.05	0	0	2.57	0.73	8.29
15	0.10	0.10	0.10	0.20	0.20	0.20	0.10	0.20	0.20	0.12	0.12	0.12	0.25	0.25	0.25	0.12	0.25	0.25
16	1.15	0.30	1.10	0.29	0.10	0.10	0.46	0.23	1.58	1.42	0.37	1.35	0.36	0.12	0.12	0.57	0.28	1.95
18	1.73	0.63	1.80	0.67	0.40	0.40	1.07	0.59	2.76	2.13	0.78	2.20	0.83	0.49	0.49	1.32	0.73	3.40
19	1.15	0.32	1.20	0.20	0	0	0.50	0.14	1.62	1.41	0.39	1.48	0.25	0	0	0.62	0.17	1.99
20	2.01	0.64	2.10	0.54	0.20	0.20	0.93	0.43	2.90	2.47	0.79	2.58	0.66	0.25	0.25	1.14	0.53	3.57
21	0.87	0.36	0.70	0.60	0.50	0.40	0.55	0.57	1.31	1.07	0.44	0.86	0.74	0.62	0.49	0.68	0.70	1.61
23	1.25	0.42	1.30	0.30	0.10	0.10	0.60	0.24	1.72	1.54	0.52	1.60	0.37	0.12	0.12	0.74	0.30	2.11
27	1.44	0.41	1.50	0.26	0	0	0.63	0.18	2.02	1.77	0.50	1.85	0.32	0	0	0.77	0.22	2.48
31	1.15	0.32	1.20	0.20	0	0	0.50	0.14	1.62	1.41	0.39	1.48	0.25	0	0	0.62	0.17	1.99
32	0.86	0.24	0.90	0.15	0	0	0.37	0.11	1.21	1.06	0.30	1.11	0.18	0	0	0.46	0.14	1.49
34	3.90	0.76	4.81	0.17	0.15	0	1.24	0.32	5.37	4.80	0.93	5.92	0.21	0.18	0	1.53	0.39	6.61
37	3.38	0.65	4.23	0.41	0.13	0	1.07	0.28	4.62	4.16	0.80	5.20	0.50	0.16	0	1.32	0.34	5.66
TOTAL	26.40	7.81	28.34	7.10	3.48	3.10	11.93	6.19	37.89	32.48	9.59	34.84	8.75	4.28	3.81	14.70	7.61	46.61
PAJARO UNIT																		
33	0.71	0.38	1.75	0.32	2.18	0	0.80	0	0	0.87	0.47	2.16	0.39	2.68	0	0.98	0	0
35	1.03	0.54	2.53	0.47	3.15	0	1.16	0	0	1.27	0.66	3.11	0.58	3.87	0	1.43	0	0
37	0.13	0.07	0.32	0.06	0.40	0	0.15	0	0	0.16	0.09	0.39	0.07	0.49	0	0.18	0	0
38	0.98	0.52	2.42	0.45	3.01	0	1.11	0	0	1.21	0.64	2.98	0.55	3.70	0	1.37	0	0
40	0.53	0.12	1.06	0.10	0.72	0	0.27	0	0.40	0.65	0.15	1.30	0.12	0.89	0	0.33	0	0.49
41	7.75	1.83	15.79	1.51	11.38	0.28	4.10	0.01	5.90	9.53	2.25	19.42	1.86	14.00	0.34	5.04	0.01	7.26
43	0.05	0.02	0.13	0	0.20	0.07	0.03	0	0.11	0.06	0.02	0.16	0	0.25	0.09	0.04	0	0.14
44	0.10	0.04	0.26	0	0.40	0.14	0.06	0.01	0.21	0.12	0.05	0.32	0	0.49	0.17	0.07	0.01	0.26
45	0.42	0.18	1.03	0.01	1.58	0.56	0.23	0.03	0.86	0.52	0.22	1.27	0.01	1.94	0.69	0.28	0.04	1.06
46	0.05	0.02	0.13	0	0.20	0.07	0.03	0	0.11	0.06	0.02	0.16	0	0.25	0.09	0.04	0	0.14
47	0.21	0.09	0.51	0.01	0.79	0.28	0.12	0.01	0.43	0.26	0.11	0.63	0.01	0.97	0.34	0.15	0.01	0.53
TOTAL	11.96	3.81	25.93	2.93	24.01	1.40	8.06	0.06	8.02	14.71	4.68	31.90	3.59	29.53	1.72	9.91	0.07	9.88
PACHECO UNIT																		
34	3.14	0.54	4.01	0.34	0.15	0	0.91	0.23	4.29	3.86	0.66	4.93	0.42	0.18	0	1.12	0.28	5.28
36	1.74	0.30	2.27	0.19	0.08	0	0.51	0.13	2.38	2.14	0.37	2.79	0.23	0.10	0	0.63	0.16	2.93
37	2.71	0.46	3.53	0.29	0.13	0	0.78	0.20	3.68	3.33	0.57	4.34	0.36	0.16	0	0.96	0.25	4.53
40	0.34	0.05	0.46	0.03	0.02	0	0.09	0.02	0.47	0.42	0.06	0.57	0.04	0.02	0	0.11	0.02	0.58
TOTAL	7.93	1.35	10.27	0.85	0.38	0	2.29	0.58	10.82	9.75	1.66	12.63	1.05	0.46	0	2.82	0.71	13.32
UVAS UNIT																		
30	17.97	8.04	22.18	10.96	8.31	8.75	11.55	0	23.73	22.10	9.89	27.28	13.48	10.22	10.76	14.21	0	29.19
33	1.80	0.80	2.22	1.10	0.83	0.88	1.16	0	2.38	2.21	0.98	2.73	1.35	1.02	1.08	1.43	0	2.93
TOTAL	19.77	8.84	24.40	12.06	9.14	9.63	12.71	0	26.11	24.31	10.87	30.01	14.83	11.24	11.84	15.64	0	32.12

A pipeline diversion from Anderson Reservoir provides inflow to the unit. Twenty percent of the water is assumed routed to percolation ponds at Main Avenue and Hill Road; the remainder is percolated along the Madrone Channel. The total amount of artificial recharge ranges from 1 850 to 4 800 dam^3 (1,500 to 3,900 acre-feet) per year for the study period.

Pacheco Unit

The Pacheco Unit encompasses that portion of the Bolsa Subbasin that is bounded by Bolsa Road on the west, the Pajaro River on the north, and the Calaveras fault on the east.

Inflow to the Pacheco Unit includes outflow from San Felipe Lake into the Pajaro River and runoff from a small portion of the eastern slopes.

Inflow to San Felipe Lake is from Pacheco Creek using Pacheco Creek gaging station near Dunneville (USGS) and overflow from Tequisquita Slough. Outflow from San Felipe Lake was arbitrarily set at this inflow minus 11 000 dam^3 (9,000 acre-feet) per year for the purpose of this modeling effort.

Stream percolation for the Pacheco Unit ranges from zero to about 13 300 dam^3 (zero to 10,800 acre-feet) annually.

Pajaro Unit

The Pajaro Unit encompasses the valley floor between the western slopes and the Southern Pacific Railroad, from Gilroy to the Pajaro River, and also between the western slopes and Bolsa Road, from the Pajaro River south to Hollister.

Inflow to the Pajaro Unit includes Llagas Creek from the north, the Pajaro River from the east, Tick Creek and Tar Creek from the west, and the southwestern slope runoff. Outflow is at the Pajaro River near Chittenden (USGS). Stream percolation ranges from about 74 to 32 000 dam^3 (60 to 26,000 acre-feet) annually.

Land Use

Land-use data are used to estimate deep percolation and pumpage from the agricultural and urban lands. Although the study period extends from 1964 through 1973, land-use surveys are available only for 1967 and 1974; these surveys are shown on Figure 23. Certain assumptions and adjustments in land-use data were made to bring those data in line with the study period. Land use for the period 1964-67 is assumed to be similar to that of the 1967 survey. Land use for the period 1967-70 is based on the 1967 survey modified by data from the "Atlas of Urban and Regional Change" published in 1970 by the U. S. Geological Survey. Interpretation of the 1970 data assumed changes in distribution of land use in each node to

be linear. A similar interpolation was made for 1970-75, based on the 1970 Atlas combined with the 1975 survey.

The land-use data were divided into areas contiguous to the 69 nodes of the ground water model. Certain irrigated lands external to the nodal network are supplied by water pumped from wells internal to the model. These lands were added to the nodal areas to determine pumpage.

Three major groupings of land use were defined: agricultural, urban, and native vegetation. The total annual area for the three major land-use groups for the study period is shown in Table 8.

Pumpage

Agricultural and urban pumpage were determined separately for South Santa Clara Valley and are summarized in Table 9.

Agricultural pumpage (applied water) was estimated by determining the area for each crop from the land-use data and estimating the unit amount of applied water used for each crop; this value is defined as unit applied water. The value of the unit applied water is based on rooting depth, available soil moisture, potential evaporation, and precipitation. The maximum soil moisture is assumed to occur at the beginning of each year. This value is used to obtain the amount of applied water needed during the critical months to supplement the amount of precipitation required for maximum growth. The value of applied water then was increased by 20 percent to offset losses in application.

The unit values of applied water are shown on Table 10. These values become a part of the hydrologic inventory by multiplying them by the area of each respective crop grown in South Santa Clara Valley. It should be emphasized that the data are based on the full soil moisture profile during the critical months, and therefore constitute the maximum pumpage expected.

Urban pumpage was determined by multiplying the area of urban lands by the unit urban pumpage. Water delivered by Gilroy was to urban areas in cells 28, 32, 33, and 48 and that delivered by Morgan Hill was to urban areas in cells 6, 8, and 11. Urban areas in these seven cells were totaled and then divided into the total deliveries to obtain an amount of annual use per node.

Some thought was given to domestic water use throughout the remainder of South Santa Clara Valley (areas of 0.7-0.8 hectare or 1-2 acres) not designated as urban areas. About 28 percent of the population of the model area is not served municipal water by either Gilroy or Morgan Hill. The land-use distribution shows discrete urban areas in all but 14 cells. Domestic water use in those outlying areas is not considered significant.

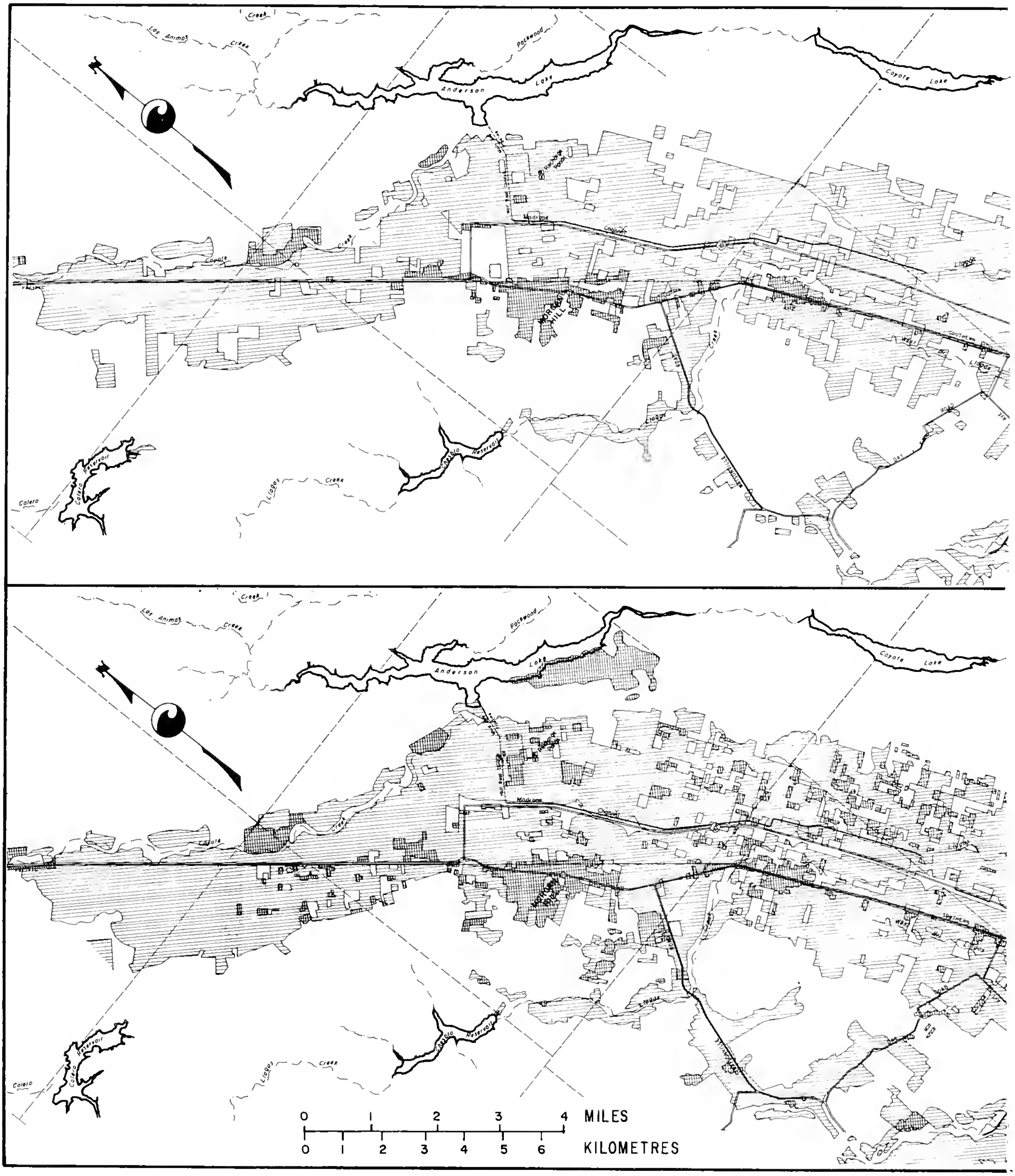
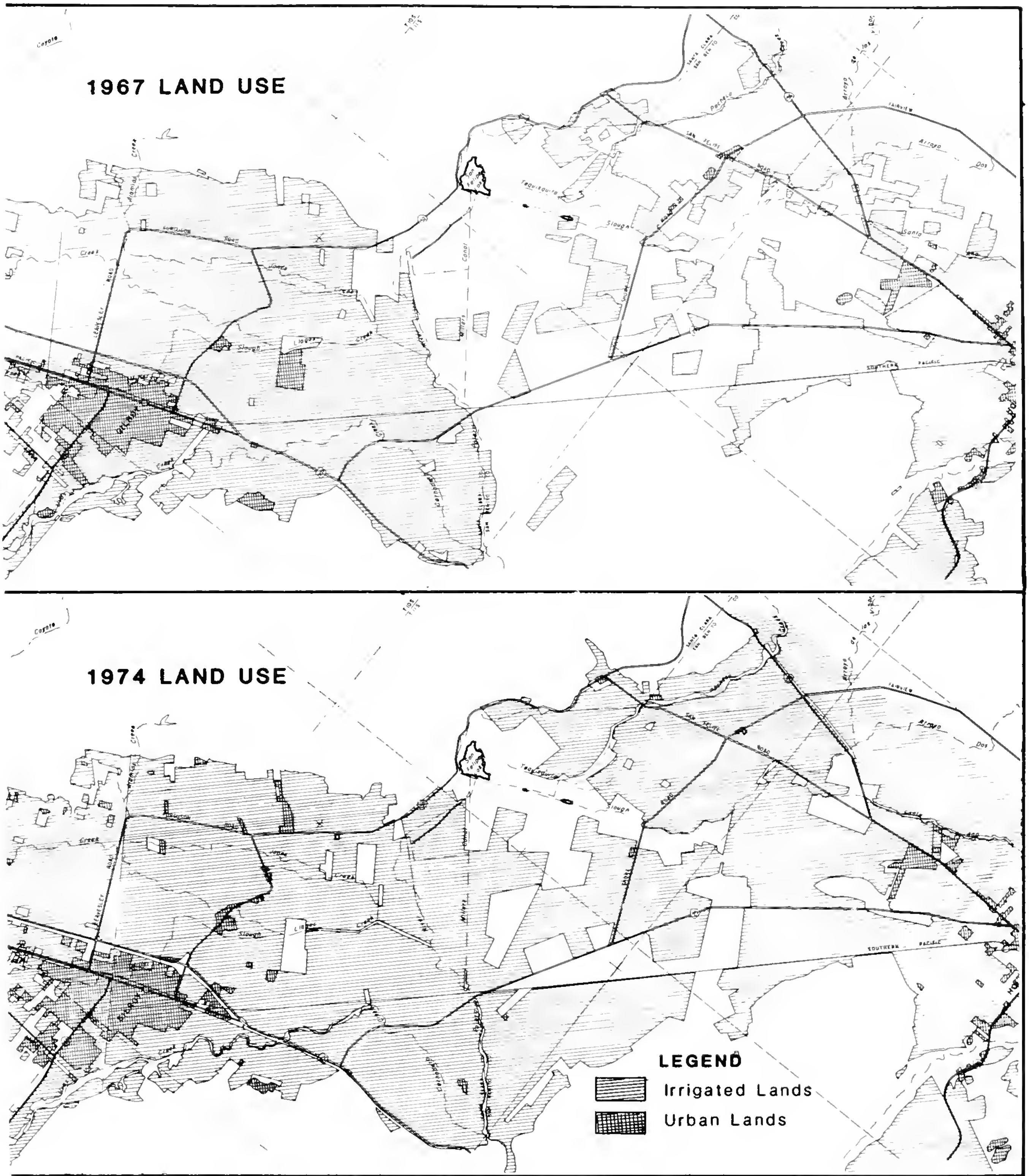


FIGURE 23.--Land Use, 1967 and



1974, South Santa Clara Valley.

Table 8. Land Use, South Santa Clara Valley

Water Year	Agriculture	Native Vegetation	Total Agriculture & Native Vegetation	Urban	Valley Total
			(Acres)		
1965	39,480	24,290	63,770	2,370	66,140
1966	39,190	24,280	63,470	2,280	65,750
1967	39,100	24,320	63,420	2,580	66,000
1968	38,630	23,930	62,560	2,880	65,440
1969	39,010	23,640	62,650	3,190	65,840
1970	38,910	23,180	62,090	3,500	65,590
1971	39,920	20,530	60,450	3,830	64,280
1972	41,600	20,620	62,220	4,160	66,380
1973	42,760	19,240	62,000	4,550	66,550
			(Hectares)		
1965	*15,977*	*9,830*	*25,807*	*959*	*26,766*
1966	*15,860*	*9,826*	*25,686*	*923*	*26,608*
1967	*15,823*	*9,842*	*25,665*	*1,044*	*26,710*
1968	*15,630*	*9,680*	*25,310*	*1,170*	*26,480*
1969	*15,790*	*9,570*	*25,360*	*1,290*	*26,650*
1970	*15,750*	*9,380*	*25,130*	*1,420*	*26,550*
1971	*16,160*	*8,310*	*24,470*	*1,560*	*26,030*
1972	*16,840*	*8,340*	*25,180*	*1,680*	*26,860*
1973	*17,300*	*7,790*	*25,090*	*1,840*	*26,930*

Most water used by manufacturers is self-produced, and is estimated to be about 6 200 dam^3 (5,000 acre-feet) annually. Because no definitive amounts are available for the study period, this value has not been included in the inventory.

Deep Percolation

Deep percolation was determined by inventory using data on land use, precipitation, evaporation, transpiration, and irrigation (applied water). The theory used to develop the inventory is summarized below.

A surface water balance is first determined for a specific position and land use with respect to time. This balance is composed of rain and applied water minus the evaporation and transpiration.

Table 9. Ground Water Pumpage, South Santa Clara Valley

Water Year	Agriculture	Urban	Total
	(Acre-feet)		
1965	95,940	18,020	113,960
1966	115,270	22,660	137,930
1967	86,280	20,470	106,750
1968	130,680	19,940	150,620
1969	96,650	19,310	115,960
1970	95,710	17,670	113,380
1971	100,350	18,000	118,350
1972	127,360	18,380	145,740
1973	98,190	16,510	114,700
Total	946,430	170,960	1,117,390
	(Cubic Dekametres)		
1965	*118,342*	*22,228*	*140,570*
1966	*142,185*	*27,951*	*170,136*
1967	*106,426*	*25,249*	*131,675*
1968	*161,194*	*24,595*	*185,789*
1969	*119,218*	*23,819*	*143,037*
1970	*118,058*	*21,796*	*139,854*
1971	*123,782*	*22,203*	*145,985*
1972	*157,099*	*22,672*	*179,771*
1973	*121,117*	*20,365*	*141,482*
Total	*1,167,421*	*210,878*	*1,378,299*

Each type of crop grows within a certain depth of soil, called the root zone. The net water from the surface water balance is infiltrated from the surface to the root zone and becomes a part of the soil moisture in storage. The crop has a capability of using stored moisture within its root zone for transpiration. If the plant cannot use all the water percolating into the root zone, some of the water will be stored in the root zone for later use. The portion of water in excess of that held by the soil percolates downward below the root zone and eventually recharges the ground water body. Once the water has moved below the root zone it becomes deep percolation, and is no longer available to crops.

Table 11 gives the deep percolation through pervious soils for each crop for each year of the study period. Table 12 gives similar data for impervious soils.

Table 10. Unit Values of Applied Irrigation Water, South Santa Clara Valley

Crop	Water Year 1965	1966	1967	1968	1969	1970	1971	1972	1973
	(Acre-feet per acre)								
Deciduous	2.31	2.91	2.33	3.68	2.46	2.43	2.46	3.23	2.20
Grain	0	0.32	0.42	0.10	0.21	0.21	0.21	0.32	0.21
Pasture	3.68	3.98	3.13	3.75	3.73	3.70	3.84	4.09	3.75
Misc. Row	2.43	2.74	1.88	2.85	2.47	2.45	2.58	2.96	2.49
Sugar Beets	2.50	2.79	2.38	2.99	2.49	2.58	2.48	3.42	2.58
Tomatoes	2.29	2.93	1.74	2.99	2.34	2.33	2.45	3.18	2.34
Vineyard	0.91	1.79	1.13	2.43	1.74	1.48	1.87	2.35	1.35
	(Cubic dekametres per hectare)								
Deciduous	*7.04*	*8.86*	*7.10*	*11.21*	*7.50*	*7.40*	*7.50*	*9.84*	*6.70*
Grain	*0*	*0.98*	*1.27*	*0.30*	*0.64*	*0.64*	*0.64*	*0.98*	*0.64*
Pasture	*11.21*	*12.13*	*9.54*	*11.43*	*11.37*	*11.27*	*11.70*	*12.46*	*11.43*
Misc. Row	*7.40*	*8.35*	*5.73*	*8.68*	*7.53*	*7.47*	*7.86*	*9.02*	*7.59*
Sugar Beets	*7.62*	*8.50*	*7.25*	*9.11*	*7.59*	*7.86*	*7.56*	*10.42*	*7.86*
Tomatoes	*6.98*	*8.93*	*5.30*	*9.11*	*7.13*	*7.10*	*7.47*	*9.69*	*7.13*
Vineyard	*2.77*	*5.45*	*3.44*	*7.40*	*5.30*	*4.51*	*5.70*	*7.16*	*4.11*

Change in Storage

Change in storage at any given node is the product of: 1) the change in depth to ground water between the beginning and the end of the study period; 2) the area of the cell; and 3) the specific yield at the average depth of water level. The change in storage may be represented by the equation:

$$\Delta S = \Delta d \cdot s \cdot A,$$

where ΔS = Change in storage,

Δd = Change in depth to ground water,

s = Average specific yield, and

A = Surface area of the cell.

Historic Data

The change in depth to ground water of each node was developed from historic ground water levels of the wells within each cell.

Table 11. Deep Percolation in Pervious Soils, South Santa Clara Valley

Water Year	Deciduous	Beets	Grain	Truck and Field	Tomatoes	Pasture	Vineyard	Irrigated Total	Native Vegetation	Urban
					(Acre-Feet)					
1964-65	6,261.80	375.68	1.43	2,515.35	1,822.13	3,158.93	203.30	14,338.62	5,546.64	465.45
1965-66	7,731.45	424.78	1.70	2,206.32	2.415.70	3,259.89	293.48	16,333.32	2,236.93	243.92
1966-67	14,108.03	787.17	0	3,767.05	2,130.83	4,581.73	547.57	25,922.38	12,487.05	1,380.15
1967-68	15,038.81	468.39	4.54	2,598.22	2,612.95	2,238.62	916.20	23,877.73	52.06	172.98
1968-69	25,679.89	1,151.52	751.68	8,807.78	6,020.03	6,601.91	1,426.32	50,439.13	23,499.93	2,321.41
1969-70	7,576.87	549.43	279.62	3,525.70	2,355.49	3,499.66	527.79	18,314.56	5,330.42	624.46
1970-71	5,809.99	483.23	486.51	4,070.75	2,741.56	3,788.72	413.14	17,793.90	5,058.81	752.14
1971-72	6,693.11	635.50	124.93	3,714.23	3,922.60	2,703.88	826.11	18,620.36	442.75	291.34
1972-73	10,001.43	1,434.29	1,927.42	9,312.82	5,864.55	5,840.94	528.37	34,909.82	11,827.24	2,034.45
TOTAL	98,901.38	6,309.99	3,577.83	40,518.22	29,885.84	35,674.28	5,682.28	220.549.82	66,481.81	8,286.31
					(Cubic Dekametres)					
1964-65	*7,723.93*	*463.40*	*1.76*	*3,102.69*	*2,247.60*	*3,896.54*	*250.77*	*17,686.69*	*6,841.78*	*574.13*
1965-66	*9,536.74*	*523.97*	*2.10*	*2,721.50*	*2,979.77*	*4,021.07*	*362.00*	*20,147,15*	*2,759.25*	*300.88*
1966-67	*17,402.26*	*970.97*	*0*	*4,646.66*	*2,628.38*	*5,651.56*	*675.43*	*31,975.26*	*15,402.78*	*1,702.42*
1967-68	*18,550.37*	*577.76*	*5.60*	*3,204.91*	*3,223.07*	*2,761.34*	*1,130.13*	*29,453.18*	*64.22*	*213.37*
1968-69	*31,676.14*	*1,420.40*	*927.20*	*10,864.40*	*7,425.71*	*8,143.46*	*1,759.36*	*62,216.67*	*28,987.16*	*2,863.46*
1969-70	*9,346.07*	*677.72*	*334.91*	*4,348.95*	*2,905.50*	*4,316.83*	*651.03*	*22,591.01*	*6,575.07*	*770.27*
1970-71	*7,166.62*	*596.06*	*600.11*	*5,021.27*	*3,381.71*	*4,673.39*	*509.61*	*21,948.77*	*6,240.04*	*927.76*
1971-72	*8,255.95*	*783.89*	*154.10*	*4,581.50*	*4,838.53*	*3,335.23*	*1,019.01*	*22,968.21*	*546.13*	*359.37*
1972-73	*12,336.76*	*1,769.20*	*2,377.47*	*11,487.36*	*7,233.92*	*7,204.80*	*651.75*	*43,061.26*	*14,588.90*	*2,509.49*
TOTAL	*121,994.84*	*7,783.37*	*4,413.25*	*49,979.24*	*36,864.19*	*44,004.22*	*7,009.09*	*272,048.20*	*82,005.33*	*10,221.15*

The following two sources were used to develop these data:

1. Ground Water Level Data, 1924-77, published by the Santa Clara Valley Water District (SCVWD) in August 1977.

   A detailed report consisting of historic ground water level data of wells located throughout the major valley areas of Santa Clara County. Hydrographs and ground water contour maps obtained from SCVWD were also used in developing the required ground water elevations for the Coyote Basin and the portion of South Santa Clara Valley included in the study area.

2. Ground water level measurement data from the San Joaquin District, Department of Water Resources.

   Used in developing ground water elevations for that portion of San Benito County included in the study area. The well measurements were made either by San Benito County or by the San Joaquin District of DWR.

Procedure

Measurement data showing ground water elevations ideally should be complete for the entire study period. These data should include

Table 12. Deep Percolation in Impervious Soils, South Santa Clara Valley

Water Year	Deciduous	Beets	Grain	Truck and Field	Tomatoes	Pasture	Vine-yard	Irrigated Total	Native Vegetation	Urban
					(Acre-Feet)					
1964-65	1,158.40	56.88	0.31	307.71	305.88	211.66	70.30	2,111.14	843.45	165.76
1965-66	733.98	35.78	0.39	196.19	195.83	132.95	43.98	1,339.10	538.08	103.87
1966-67	1,786.57	90.69	0	490.91	497.04	333.31	108.55	3,307.07	1,337.63	282.90
1967-68	570.88	30.57	9.87	180.84	167.40	106.75	36.40	1,102.71	431.42	105.33
1968-69	1,643.40	91.17	60.47	633.82	573.88	330.73	107.16	3,440.63	1,359.62	361.39
1969-70	924.39	57.89	55.63	413.88	358.55	191.74	58.40	2,060.48	794.35	237.34
1970-71	736.31	55.26	68.81	389.39	346.10	172.28	47.20	1,815.35	631.49	221.59
1971-72	383.73	33.98	54.37	241.87	216.70	98.98	24.69	1,054.32	343.63	133.57
1972-73	947.38	99.61	193.71	709.42	642.93	268.04	61.49	2,922.58	877.23	402.27
TOTAL	8,885.04	551.83	443.56	3,564.03	3,304.31	1,846.44	558.17	19,153.38	7,156.90	2,014.02
					(Cubic Dekametres)					
1964-65	*1,428.89*	*70.16*	*0.38*	*379.56*	*377.30*	*261.08*	*86.72*	*2,604.09*	*1,040.40*	*204.46*
1965-66	*905.36*	*44.14*	*0.48*	*242.00*	*241.56*	*163.99*	*54.25*	*1,651.78*	*663.72*	*128.12*
1966-67	*2,203.73*	*111.86*	*0*	*605.54*	*613.10*	*411.14*	*133.90*	*4,079.27*	*1,649.97*	*348.96*
1967-68	*704.18*	*37.71*	*12.17*	*223.06*	*206.49*	*131.68*	*44.90*	*1,360.19*	*532.16*	*129.92*
1968-69	*2,027.13*	*112.46*	*74.59*	*781.82*	*707.88*	*407.96*	*132.18*	*4,244.02*	*1,677.09*	*445.77*
1969-70	*1,140.23*	*71.41*	*68.62*	*510.52*	*442.27*	*236.51*	*72.04*	*2,541.60*	*979.83*	*292.76*
1970-71	*908.24*	*68.16*	*84.88*	*480.31*	*426.91*	*212.51*	*58.22*	*2,239.23*	*778.94*	*273.33*
1971-72	*473.33*	*41.91*	*67.07*	*298.35*	*267.30*	*122.09*	*30.45*	*1,300.50*	*423.87*	*164.76*
1972-73	*1,168.60*	*122.87*	*238.94*	*875.07*	*793.04*	*330.63*	*75.85*	*3,605.00*	*1,082.06*	*496.20*
TOTAL	*10,959.69*	*680.68*	*547.13*	*4,396.23*	*4,075.85*	*2,277.59*	*688.51*	*23,625.68*	*8,828.04*	*2,484.30*

spring measurements, which are vitally important because maximum ground water elevations during February through June are used in calculating the change in depth to ground water during the period of minimal pumping. Furthermore, during the spring months, the ground water basin recovers from any excessive pumping that might have occurred during the preceding fall. In addition, cones of depression are minimized, and the measured water levels thus tend to reflect an essentially unstressed condition.

Ideally, a well used for measuring ground water elevations should be located at or near the node point, or center of the cell. However, in many cases, this was not possible. Therefore, data from the well closest to the node point were assigned to represent the respective cell. If there were two or more wells in a cell, all located away from the node point, the historic maximum spring ground water elevations from these wells were used to interpolate the ground water elevation at the node point.

In some cases historic spring ground water elevations or levels were not available. Water-surface elevations for these cells were synthesized by using either trends indicated by hydrographs of nearby wells, by using ground water contour maps, or both.

The yearly change in ground water level is the difference in the spring ground water elevations for two consecutive years under

consideration. The change is positive or negative depending upon whether there is an increase or decrease of ground water in storage.

Average Specific Yield

Average specific yield values for all cells except those in Coyote Valley were obtained from the GEOLOG computer program (Ford and Finlayson, 1974), which computes these values from data in the water well log file. Average specific yield values for Coyote subbasin (Cells 49 through 69) were obtained from data developed by the Santa Clara Valley Water District for its Coyote ground water model.

Results

Yearly changes in ground water storage and the total change in storage for the study period are shown in Table 13.

Adjustment of the Model

A computer model is an idealized simulator of a prototype system; however, normally it will not accurately simulate the prototype the first time that it is run. Therefore, the model is adjusted until it satisfactorily simulates the historic hydrologic record. At that point the model is considered verified, and it can then be used as a planning tool by superimposing new conditions or new hydrologic events to describe future conditions and responses within the ground water basin.

In the process of adjusting a ground water model, storage coefficients, specific yields, and transmissivities are adjusted within acceptable ranges until the model accurately simulates the prototype basin within the required margin of error. Changing the physical dimensions of each cell or branch, and/or the hydrologic input data, are necessary only when these adjustments fail to bring the model into verification.

Ground water elevations for each node are used as indicators of adjustment. Historic ground water elevations for the study period are matched against the calculated elevations for each node. The model is then adjusted until the calculated ground water elevations match the historic elevations throughout the study period.

One major problem with full verification of the model is the determination of the correct net annual flows. The flows that were used were compiled from the computerized hydrologic data developed for the basin. These calculated flows were out of balance with the measured change in storage by about 222 000 dam^3 (180,000 acre-feet) for the total study period or an average of 24 600 dam^3 (20,000 acre-feet) per year. Two methods were used

Table 13. Changes in Ground Water Storage, South Santa Clara Valley

Node Number	Water Year								
	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	1971-72	1972-73
					(Acre-Feet)				
1	-52	33	178	-242	239	-118	111	-178	185
2	-138	76	254	18	857	-478	-166	-212	583
3	-175	35	200	-185	554	36	-12	-777	916
4	-472	-108	504	350	1,961	-519	1,060	-802	1,037
5	-386	39	1,040	-17	995	-493	-468	-611	690
6	-65	40	379	-104	494	-93	-245	-407	491
7	-535	-7	1,390	-168	3,456	-2,171	-321	-1,216	416
8	-260	73	466	-67	2,239	-656	-920	-322	178
9	-286	337	654	-283	1,051	-107	-305	-1,182	519
10	-240	-528	162	-205	1,074	-346	-396	-729	541
11	-70	64	356	-203	576	-40	-317	-337	260
12	48	81	583	841	1,182	-74	-342	-1,016	406
13	-210	5	917	-306	1,240	-333	-296	-918	869
14	-112	74	708	-389	885	-189	-279	-616	578
15	-225	-273	1,920	-1,579	1,570	58	-332	-1,334	113
16	-289	-249	2,454	-1,621	1,653	-76	-710	-1,190	810
17	-66	-361	1,363	-989	921	-152	-106	-864	192
18	-340	-765	2,178	-2,095	2,011	-1,676	1,020	-754	510
19	74	-965	2,079	-1,782	1,931	-772	-39	-1,025	854
20	0	-776	2,182	-2,091	2,182	-1,096	-232	-1,390	1,267
21	126	-1,345	3,667	-3,667	3,505	-4,003	2,452	-727	1,147
22	-77	-1,161	2,232	-1,693	2,291	-2,474	1,578	-1,185	1,486
23	-86	-315	2,422	-1,431	1,365	-1,979	1,141	-867	277
24	108	-324	2,552	-2,552	2,119	-585	-78	-1,336	411
25	-135	-470	1,774	-965	965	0	-58	-1,136	426
26	73	-263	907	-907	720	0	146	-665	55
27	-76	-933	1,196	-673	755	-297	-351	-671	585
28	-634	-713	2,006	-2,245	1,476	0	-642	-1,140	-581
29	-131	-275	941	-807	672	0	-93	-583	272
30	-193	-429	1,595	-2,259	1,290	0	-411	-894	680
31	190	-690	871	-759	1,205	-90	-369	-456	490
32	-266	-142	1,108	-964	373	-360	-617	-607	729
33	-542	-111	1,451	-1,005	1,437	-287	-358	-829	829
34	481	-1,663	1,045	-1,350	1,350	2,703	-1,414	-832	1,247
35	-195	1,311	-546	-769	1,311	2,267	-2,631	-949	769
36	-83	-83	3,476	195	-110	-254	0	458	0
37	99	-635	846	-669	1,235	-147	-236	-316	222
38	-145	-434	507	-684	1,665	941	-1,376	-434	507
39	-468	1,403	701	628	340	-1,466	468	-234	-234
40	0	60	504	67	-67	-193	0	395	0
41	622	-974	-581	-1,020	5,573	510	-408	-408	408
42	667	309	34	139	-139	-395	221	-1,001	-231
43	232	-762	762	212	-696	-1,178	0	894	-289
44	257	-381	1,060	259	-676	-649	-123	197	-364
45	-51	213	116	61	-61	116	0	-260	-49
46	181	188	196	0	0	-196	-543	-478	2,315
47	-188	-137	-514	-143	1,044	-1,323	-1,342	631	133
48	632	970	-164	826	-330	-656	-647	-1,090	453
49	-99	99	177	99	414	-374	-59	-59	335
50	-210	325	338	223	1,051	-976	-128	-124	377
51	89	30	238	-209	596	-387	-268	238	596
52	-70	37	316	-236	862	-303	-326	-316	606
53	105	580	316	-316	1,107	-527	-527	-264	1,001
54	165	-198	790	-732	1,351	-716	-390	-481	1,330
55	116	155	155	-310	776	-272	-349	-78	582
56	195	-98	142	-498	1,005	-268	-386	0	634
57	131	-86	317	-494	874	-390	-263	-113	512
58	126	-41	190	-417	766	-175	7	-335	324
59	142	0	283	-566	944	-189	-142	-330	425
60	78	39	272	-43	582	-155	-427	39	427
61	7	66	101	-295	590	-232	-135	-28	243
62	31	53	66	-207	392	-132	-79	-88	216
63	-28	0	56	-112	225	-84	-169	0	225
64	5	20	69	-127	235	-96	-17	-47	88
65	20	-20	80	40	159	-80	-418	318	60
66	0	0	-42	-211	211	-84	0	-42	126
67	-31	-61	184	-18	273	-107	-6	-40	135
68	41	68	-149	86	0	-4	8	-9	15
69	15	15	-168	168	46	-46	15	0	15
Σ	-2,573	-9,918	53,862	-37,466	68,152	-25,019	-15,205	-31,162	31,790

Table 13. Changes in Ground Water Storage, South Santa Clara Valley (Continued)

Node Number	Water Year								
	1964-65	1965-66	1966-67	1968-68	1968-69	1969-70	1970-71	1971-72	1972-73
					(Cubic Dekametres)				
1	-64	41	220	-299	295	-146	137	-220	228
2	-170	94	313	22	1,057	-590	-205	-262	719
3	-216	43	247	-228	683	44	-15	-958	1,130
4	-582	-133	622	432	2,419	-640	1,308	-989	1,279
5	-476	48	1,233	-21	1,227	-497	-577	-754	851
6	-80	49	467	-128	609	-102	-302	-502	606
7	-660	-9	1,715	-207	4,263	-2,678	-396	-1,500	513
8	-321	90	575	-83	2,762	-809	-1,135	-397	220
9	-353	416	807	-349	1,296	-132	-376	-1,458	640
10	-296	-651	200	-253	1,325	-427	-488	-899	667
11	-86	79	439	-250	710	-49	-391	-416	321
12	59	100	719	1,037	1,458	-91	-422	-1,253	501
13	-259	6	1,131	-377	1,530	-411	-365	-1,132	1,072
14	-138	91	873	-480	1,092	-233	-344	-760	713
15	-278	-337	2,368	-1,948	1,937	72	-410	-1,645	139
16	-356	-307	3,027	-2,000	2,039	-94	-876	-1,468	999
17	-81	-445	1,681	-1,220	1,136	-187	-131	-1,066	237
18	-419	-944	2,687	-2,584	2,481	-2,067	1,258	-930	629
19	91	-1,190	2,564	-2,198	2,382	-952	-48	-1,264	1,053
20	0	-957	2,691	-2,579	2,691	-1,352	-286	-1,715	1,563
21	155	-1,659	4,523	-4,523	4,323	-4,938	3,025	-897	1,415
22	-95	-1,432	2,753	-2,088	2,826	-3,052	1,946	-1,462	1,833
23	-106	-389	2,988	-1,765	1,634	-2,441	1,407	-1,069	342
24	133	-400	3,148	-3,148	2,614	-722	-96	-1,648	507
25	-167	-580	2,188	-1,190	1,190	0	-72	-1,401	525
26	90	-324	1,119	-1,119	888	0	180	-820	68
27	-94	-1,151	1,475	-830	931	-366	-433	-828	722
28	-782	-879	2,474	-2,769	1,821	0	-792	-1,406	-717
29	-162	-339	1,161	995	829	0	-115	-719	336
30	-239	-529	1,967	-2,786	1,591	0	-507	-1,103	839
31	234	-851	1,074	-936	1,486	-111	-455	-562	493
32	-328	-175	1,367	-1,189	460	-444	-761	-749	899
33	-669	-137	1,790	-1,240	1,773	-354	-442	-1,023	1,023
34	593	-2,051	1,289	-1,665	1,665	3,334	-1,744	-1,026	1,538
35	-241	1,617	-673	-949	1,617	2,796	-3,245	-1,171	949
36	-102	-102	4,288	241	-136	-313	0	565	0
37	122	-783	1,044	-825	1,523	-181	-291	-390	274
38	-179	-535	625	-844	2,054	1,161	-1,697	-535	625
39	-577	1,731	865	775	419	-1,808	577	-289	-289
40	0	74	622	83	-83	-238	0	487	0
41	767	-1,201	-717	-1,258	6,874	629	-503	-503	503
42	823	381	42	171	-171	-487	273	-1,235	-285
43	296	-940	940	262	-859	-1,453	0	1,103	-356
44	317	-470	1,308	321	-834	-801	-152	243	-449
45	-63	263	143	75	-75	-143	0	-321	-60
46	223	232	242	0	0	-242	-670	-590	2,856
47	-232	-169	-634	-176	1,288	-1,632	-1,655	778	164
48	780	1,196	-202	1,019	-407	-809	-798	-1,345	559
49	-122	122	218	122	511	-461	-73	-73	413
50	-259	401	417	275	1,309	-1,204	-158	-153	1,082
51	110	37	294	-258	735	-477	-331	294	735
52	-86	46	390	-291	1,063	-374	-402	-390	748
53	130	715	390	-390	1,365	-650	-650	-326	1,235
54	204	-244	974	-903	1,666	-883	-481	-593	1,641
55	143	191	191	-382	957	-336	-430	-96	718
56	241	-121	175	-614	1,240	-331	-476	0	782
57	162	-106	391	-609	1,078	-481	-324	-139	632
58	155	-51	234	-514	945	-216	9	-413	400
59	175	0	349	-698	1,164	-233	-175	-407	524
60	96	48	336	-53	718	-191	-527	48	527
61	9	81	125	-364	728	-286	-167	-35	300
62	38	65	81	-255	464	-163	-97	-109	266
63	-35	0	69	-138	278	-104	-208	0	278
64	6	25	85	157	290	-118	-21	-58	109
65	25	-25	99	49	196	-39	-516	392	74
66	0	0	-52	-260	260	-104	0	-52	155
67	-38	-75	227	-22	337	-132	-7	-49	167
68	51	84	-184	106	0	-5	10	-11	19
69	19	19	-207	207	57	-57	19	0	19
Σ	-3,174	-12,234	66,439	-46,214	84,065	-30,861	-18,706	-39,672	39,213

Table 14. Corrected Hydrologic Balance, South Santa Clara Valley

Water Year	Deep Perco-lation	Stream Perco-lation	Artificial Perco-lation	Waste Water Disposal	Subsurface Inflow/ Outflow	Applied Water	Urban Use	Sum (Balance)	Change in Storage
					(Acre-Feet)				
1964-65	23,471	47,650	2,100	6,400	34,997	75,715	14,337	24,565	- 2,573
1965-66	20,795	16,180	1,600	6,690	24,663	92,216	18,132	-40,420	- 9,918
1966-67	44,717	60,010	1,500	6,690	39,056	67,879	16,231	67,863	53,862
1967-68	25,742	15,530	3,500	3,200	24,450	104,542	15,954	-48,074	-37,466
1968-69	81,422	28,220	3,200	3,400	28,617	77,324	15,445	52,091	68,152
1969-70	27,362	14,250	3,100	3,600	24,029	76,565	14,137	-18,360	-25,019
1970-71	26,273	26,850	2,100	4,090	28,167	80,278	14,396	- 7,194	-15,165
1971-72	20,886	10,100	3,500	6,000	22,667	101,889	14,705	-53,441	-32,162
1972-73	52,974	55,290	3,800	5,890	37,506	78,550	13,211	63,698	31,790
Total	323,642	274,080	24,400	45,960	264,152	754,958	136,548	40,728	31,501
					(Cubic Dekametres)				
1964-65	*28,951*	*58,776*	*2,590*	*7,894*	*43,168*	*93,394*	*17,685*	*30,301*	*- 3,174*
1965-66	*25,651*	*19,958*	*1,974*	*8,252*	*30,422*	*113,748*	*22,366*	*-49,858*	*-12,234*
1966-67	*55,158*	*74,022*	*1,850*	*8,252*	*48,175*	*83,729*	*20,021*	*83,709*	*66,439*
1967-68	*31,753*	*19,156*	*4,317*	*3,947*	*30,159*	*128,953*	*19,679*	*-59,299*	*-46,214*
1968-69	*100,434*	*34,809*	*3,947*	*4,194*	*35,299*	*95,379*	*19,051*	*64,254*	*84,065*
1969-70	*33,751*	*17,577*	*3,824*	*4,441*	*29,640*	*94,443*	*17,438*	*-22,647*	*-30,861*
1970-71	*32,408*	*33,120*	*2,590*	*5,045*	*34,744*	*99,023*	*17,757*	*- 8,874*	*-18,706*
1971-72	*25,763*	*12,458*	*4,317*	*7,401*	*27,960*	*125,680*	*18,139*	*-65,919*	*-39,672*
1972-73	*65,343*	*68,200*	*4,687*	*7,265*	*46,263*	*96,891*	*16,296*	*78,571*	*39,213*
Total	*399,212*	*338,076*	*30,096*	*56,691*	*325,831*	*931,240*	*168,432*	*50,238*	*38,856*

to adjust this hydrologic imbalance. First, both the agricultural and urban pumpage were reduced by 20 percent. Second, a subsurface inflow value of 12 300 dam^3 (10,000 acre-feet) per year was added on a pro rata basis to each cell based on the ratio of length of external cell boundary divided by the entire length of the model boundary. The adjusted values for the hydrologic balance are shown on Table 14.

Present Status of the Model

The South Santa Clara Valley ground water model could not be verified due to a lack of historic data. The availability and quality of historic data are shown on Table 15 and on Figure 24. In spite of these shortcomings, the model, as it is now developed, can be used as a tool for general analysis of basin operational plans.

Figure 25 shows a number of ground water hydrographs for a selected set of nodes in the final adjustment run of the model. Figure 26 shows contour plots of the historic and calculated ground water levels for the fifth and ninth years of the study.

Table 15. Nodal Analysis of Ground Water Model, South Santa Clara Valley

Node Number	Historic Water-level Record	Maximum Deviation of Computed Water Level: Below Historic Record, Feet	Metres	Year	Above Historic Record, Feet	Metres	Year	Remarks
1	1965-69	25	8	1966	--	--	--	Fair match, 2-8 metres (8-25 feet) below.
2	---	--	--	--	--	--	--	No historic data.
3	1965-73	31	9	1970	--	--	--	Fair match, 5-9 metres (15-31 feet) below.
4	1965-73	20	6	1969	21	6	1972	Matched, 1965-68.
5	1965-73	26	8	1969	8	2	1972	Matched, 1965-68.
6	1965-73	24	7	1969	6	2	1972	Poor match, 1965-68.
7	1965-73	40	12	1969	6	2	1972	Matched, 1965-68 and 1972-73.
8	1965-70	28	9	1969	--	--	--	Matched, 1965-68.
9	1965-73	--	--	--	16	5	1972	Matched, 1968-71.
10	1965-73	26	8	1969	13	4	1966	Matched, 1972-73.
11	1965-73	--	--	--	32	10	1972	Matched, 1969-70, otherwise below.
12	1965-73	29	9	1969	11	3	1965	Matched, 1967 only.
13	1965-73	28	9	1969	--	--	--	Matched, 1-2 metres (3-5 feet) below, 1965-68 and 1972-73.
14	1965-73	30	9	1969	--	--	--	Matched, 1965-67 and 1971-73.
15	1969-73	34	10	1969	--	--	--	Matched, 7-10 metres (23-34 feet) below.
16	1969-73	41	12	1969	--	--	--	Matched, 9-12 metres (31-41 feet) below.
17	1969-73	32	10	1969	--	--	--	Unmatched, 0-10 metres (0-32 feet) below.
18	---	--	--	--	--	--	--	No historic data.
19	1969-73	44	13	1969	--	--	--	Unmatched, too low.
20	---	--	--	--	--	--	--	No historic data.
21	---	--	--	--	--	--	--	No historic data.
22	---	--	--	--	--	--	--	No historic data.
23	1969-73	21	6	1969	--	--	--	Unmatched.
24	1969-73	28	9	1969	--	--	--	Unmatched, 9 metres (28 feet) below.
25	---	--	--	--	--	--	--	No historic data.
26	1972-73	20	6	1972	--	--	--	Matched, 6 metres (20 feet) below.
27	1969-73	26	8	1970	--	--	--	Matched, 8 metres (26 feet) below.
28	1970-73	8	2	1970	--	--	--	Matched, 2 metres (8 feet) below.
29	---	--	--	--	--	--	--	No historic data.
30	---	--	--	--	--	--	--	No historic data.
31	1969-73	19	6	1971	--	--	--	Fair match, about 6 metres (19 feet) below.
32	1969-73	10	3	1973	--	--	--	Matched, 1969-72.
33	---	--	--	--	--	--	--	No historic data.
34	---	--	--	--	--	--	--	No historic data.
35	---	--	--	--	--	--	--	No historic data.
36	1965-71	7	2	1968	13	4	1965	Matched, 1966-71.
37	1969-73	16	5	1972	--	--	--	Fair match, 2-5 metres (8-16 feet) below.
38	---	--	--	--	--	--	--	No historic data.
39	---	--	--	--	--	--	--	No historic data.
40	---	--	--	--	--	--	--	No historic data.
41	---	--	--	--	--	--	--	No historic data.
42	1965-73	--	--	--	47	14	1971	Unmatched, 2-14 metres (6-47 feet) above.
43	---	--	--	--	--	--	--	No historic data.
44	1968-73	--	--	--	53	16	1970	Unmatched, 3-16 metres (10-53 feet) above.
45	---	--	--	--	--	--	--	No historic data.
46	---	--	--	--	--	--	--	No historic data.
47	1967-73	--	--	--	57	17	1971	Unmatched, 4-17 metres (12-57 feet) above.
48	---	--	--	--	--	--	--	No historic data.
49	---	--	--	--	--	--	--	No historic data.
50	1965-73	24	7	1969	10	3	1971	Matched, 1965-68.
51	---	--	--	--	--	--	--	No historic data.
52	1965-73	34	10	1969	--	--	--	Unmatched, 3-10 metres (11-34 feet) below.
53	---	--	--	--	--	--	--	No historic data.
54	1965-73	35	11	1969	--	--	--	Unmatched, 4-11 metres (12-35 feet) below.
55	---	--	--	--	--	--	--	No historic data.
56	1965-73	11	3	1969	9	3	1971	Matched, 1965-68.
57	1965-73	23	7	1969	--	--	--	Unmatched, 1-7 metres (2-23 feet) below.
58	1965-73	16	5	1969	--	--	--	Poor match, 2-5 metres (5-15 feet) below.
59	---	--	--	--	--	--	--	No historic data.
60	---	--	--	--	--	--	--	No historic data.
61	1965-73	--	--	--	12	4	1971	Poor match, 2-4 metres (5-12 feet) above.
62	1965-73	--	--	--	9	3	1971	Matched, 1965-70.
63	---	--	--	--	--	--	--	No historic data.
64	1965-73	--	--	--	13	4	1971	Matched, 1965-66.
65	---	--	--	--	--	--	--	No historic data.
66	---	--	--	--	--	--	--	No historic data.
67	1968-73	--	--	--	11	3	1971	Unmatched, computed level 3 metres (10 feet) above ground.
68	1968-73	--	--	--	18	5	1971	Unmatched, computed level 3 metres (10 feet) above ground.
69	---	--	--	--	--	--	--	No historic data.

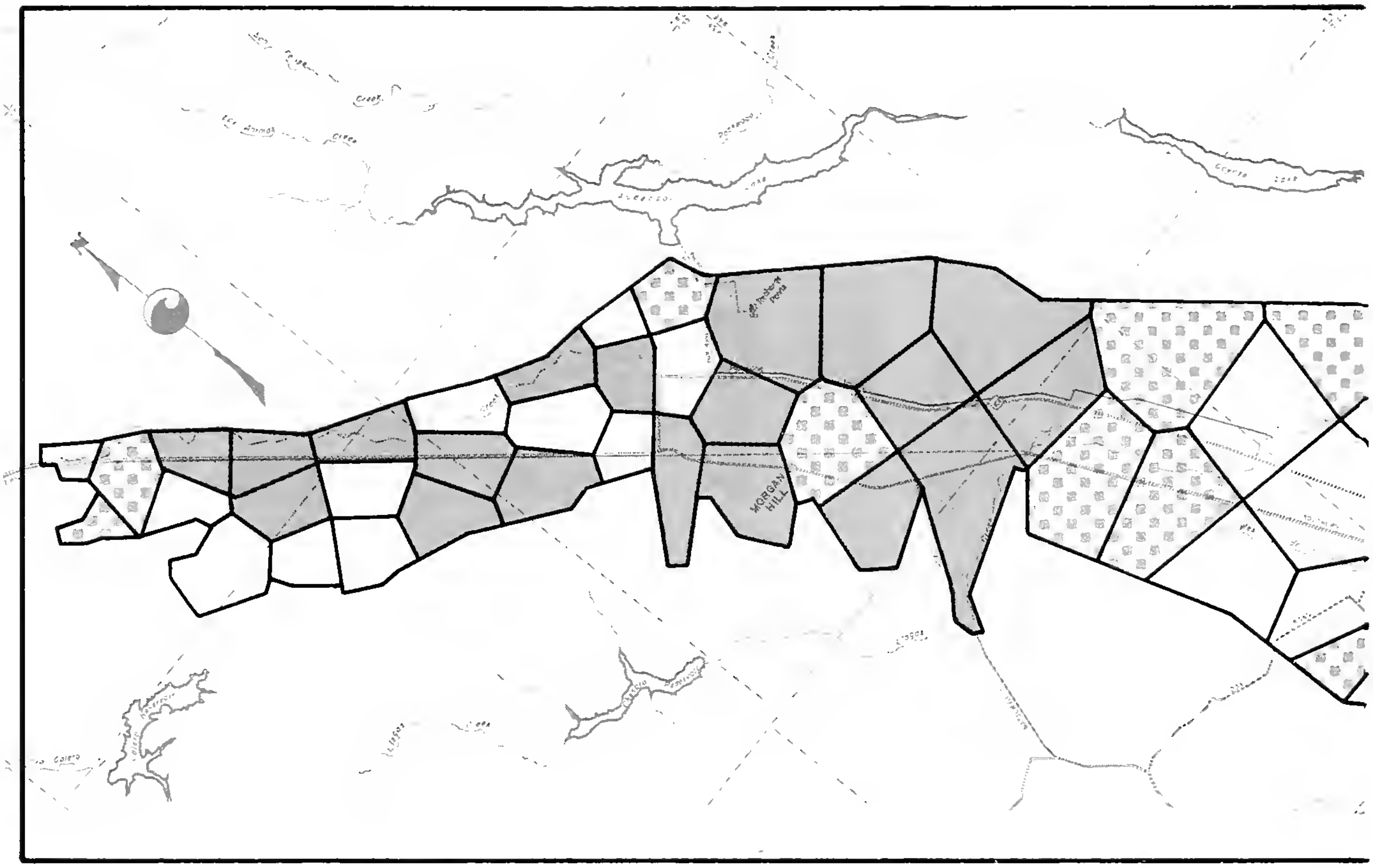
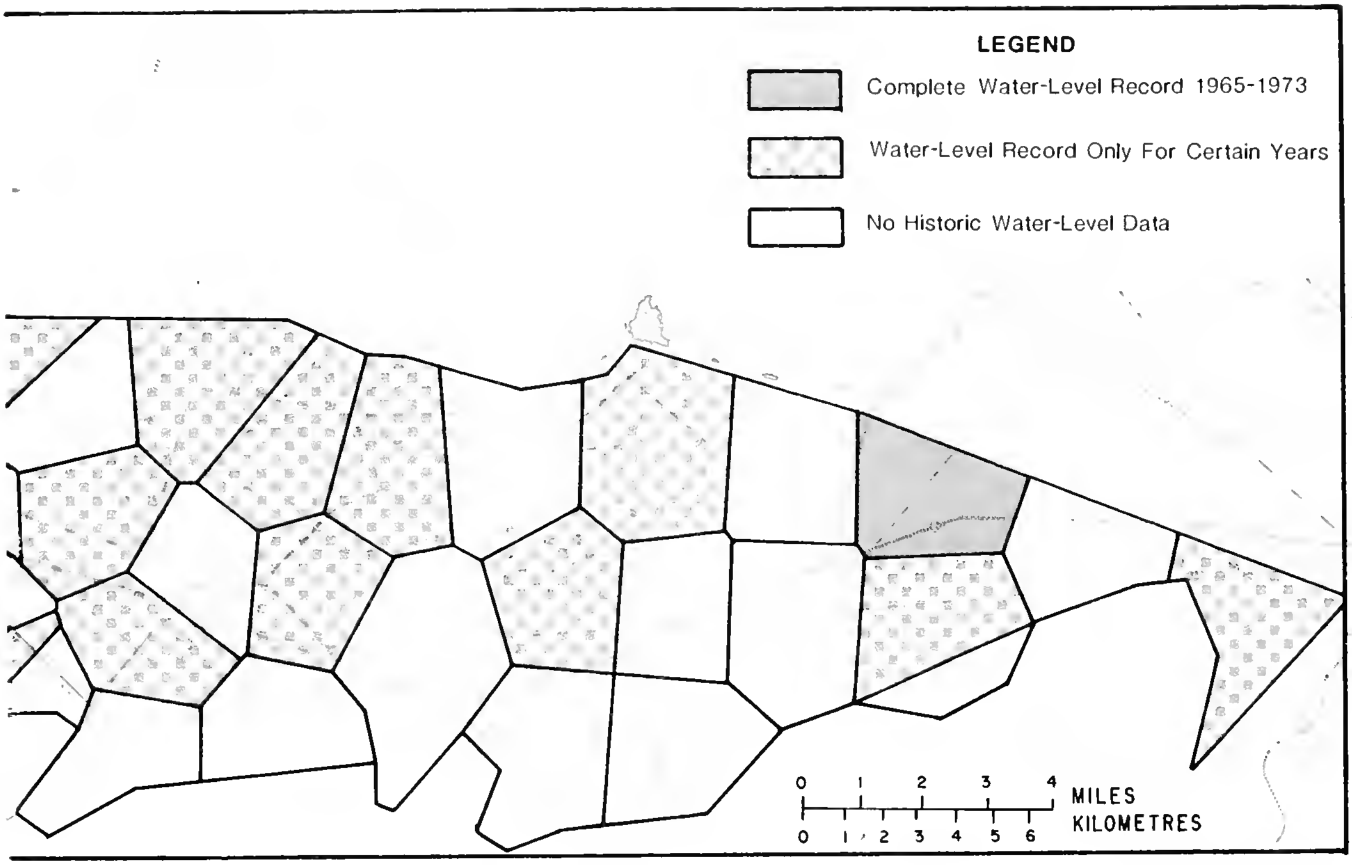


FIGURE 24.--Nodal Historic Periods of Record,

Two major differences between the model and historic ground water level records still preclude the model from being verified and are discussed below.

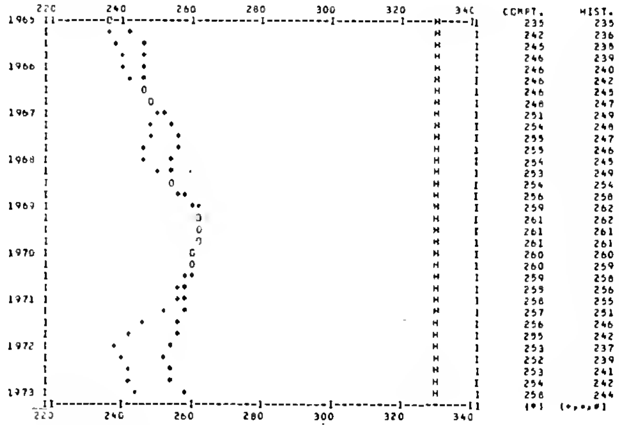
<u>Difference 1</u>: Historic water levels in the upper Llagas Subbasin (Cells 1, 4, and 9) imply that an impulse-like recharge was made to the subbasin in 1969; the hydrologic calculations do not verify this. As a result, the model-generated water levels do not agree with the historic water levels for 1969 and for two years thereafter. Historic water levels in this subbasin appear to require two years to reach equilibrium after the large impulse. The water appears to move slowly southward toward the lower part of the subbasin. The detailed hydrology in the upper Llagas Subbasin should be refined, and data for Anderson Reservoir should be reviewed for unaccounted spills to be used in streambed percolation calculations.



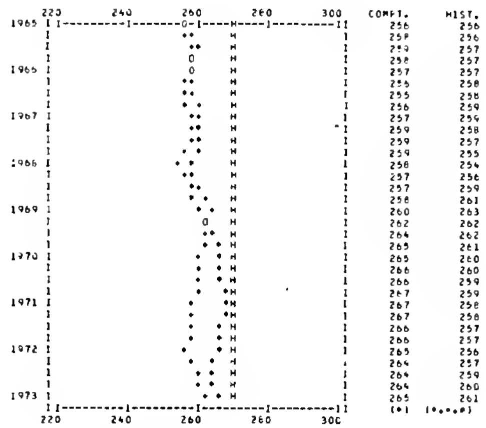
South Santa Clara Ground Water Model.

Difference 2: The hydrographs for the central portion of the Llagas Subbasin, just north of Gilroy, show a steep gradient for the historic levels; the model levels have a more gradual gradient. In previous runs of the model, efforts in adjusting transmissivities and specific yields had only a minimal effect in correcting this disagreement. This condition implies that fault-caused restrictions in flow could be occurring. Inclusion of fault restrictions in the model in this area will prove or disprove this theory.

In addition, in the southern portion of the model there is a depression formed in the historic water levels; the model was not able to simulate this. This condition also implies some degree of fault restriction. Imposing a fault boundary in this area should alleviate this problem.

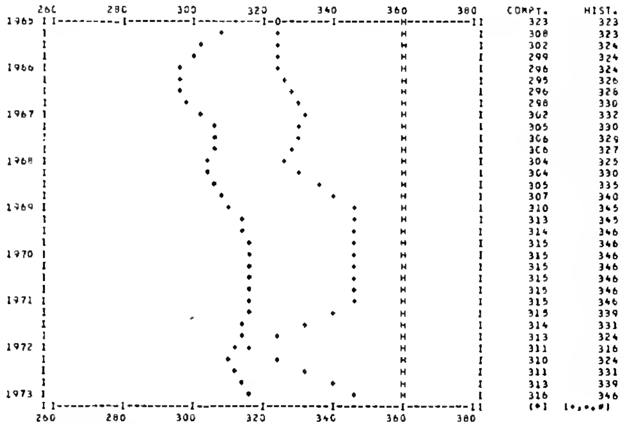


Node 9

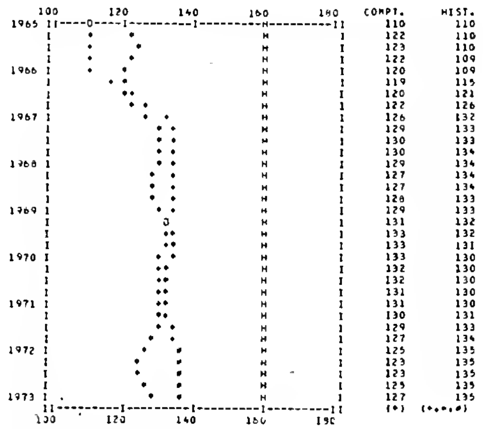


Node 62

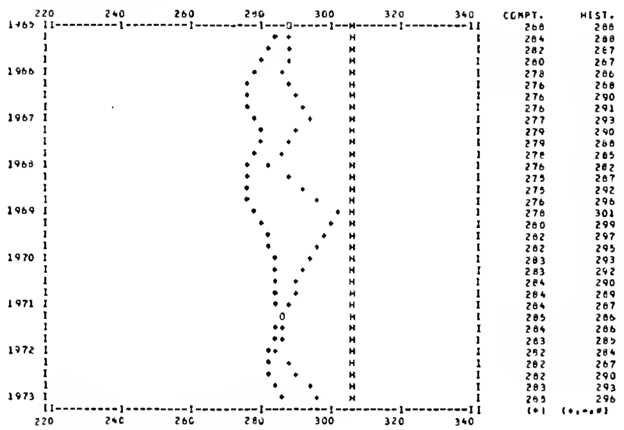
NODE TYPE 1. Full period of record; Fair to good agreement between historic and computed levels. Nodes 9, 56, 58, 62, 63, and 64.



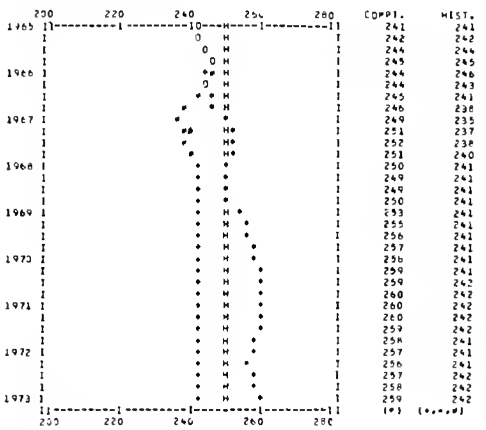
Node 3



Node 36



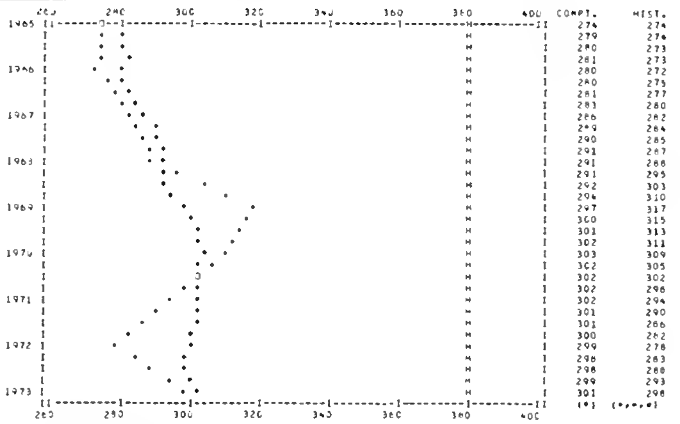
Node 57



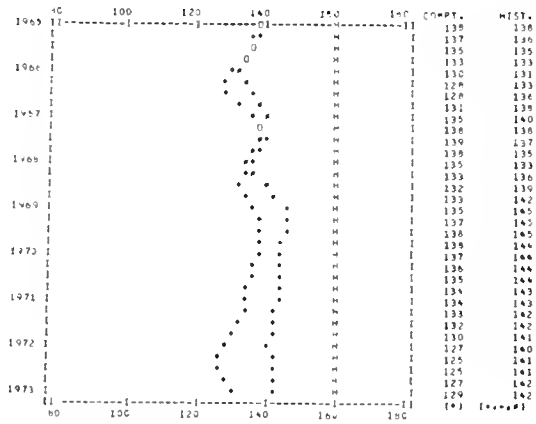
Node 68

NODE TYPE 2. Six to nine years of historic record; Up to seven years of fair to good agreement between historic and computed levels. May have up to 4 years of nonagreement. Nodes 3, 13, 36, 50, 57, 67, and 68.

FIGURE 25.--Computer-Generated Hydrographs,

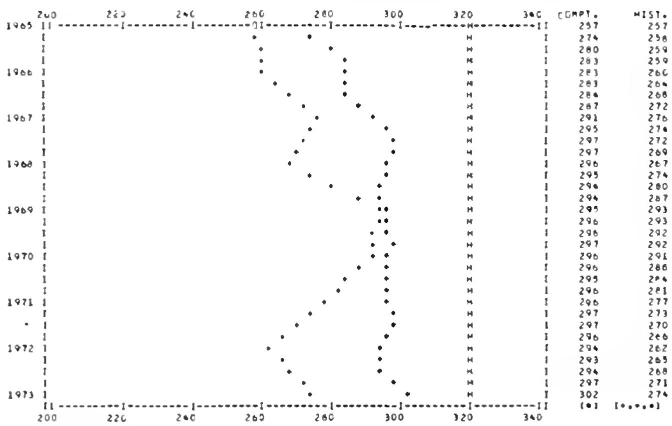


Node 4

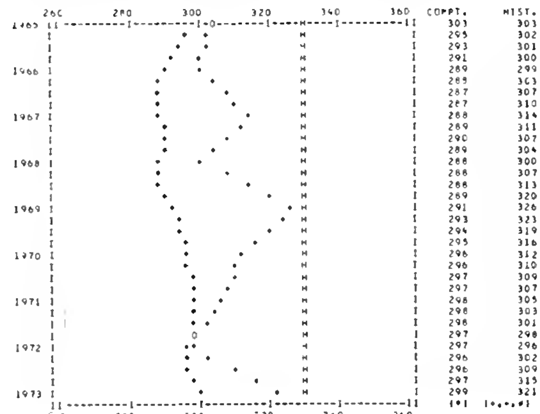


Node 37

NODE TYPE 3. Four to nine years of historic record; Up to five years of poor to good agreement between computed levels. May have up to 6 years of nonagreement. All nodes except those of types 1, 2, 4, or 5.



Node 11

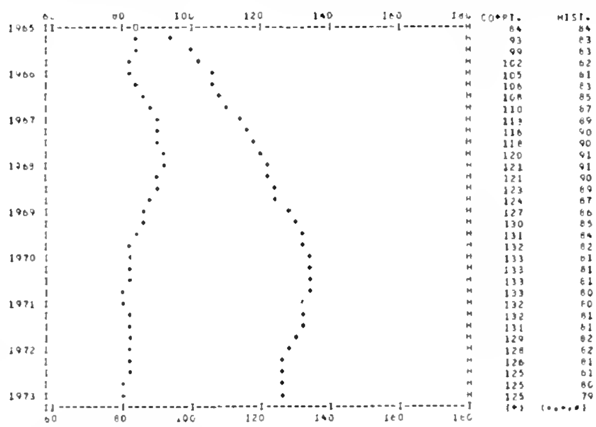


Node 54

NODE TYPE 4. Five to nine years of historic record; Up to four years of poor to fair agreement between historic and computed levels. May have 2 to 9 years of nonagreement. Nodes 5, 11, 23, 42, 52, and 54.

LEGEND

- + HISTORIC WATER LEVEL ACTUAL
- ≠ HISTORIC WATER LEVEL ESTIMATED
- * COMPUTED WATERLEVEL
- 0 COMPUTED AND HISTORIC WATER LEVELS MATCHED
- H GROUND SURFACE



Node 44

NOTE: Scale on hydrographs, Horizontal elevation in feet. Vertical in years

NODE TYPE 5. Two to seven years of historic record: Little or no agreement between historic and computed levels. Nodes 26, 44, and 47.

South Santa Clara Ground Water Model.

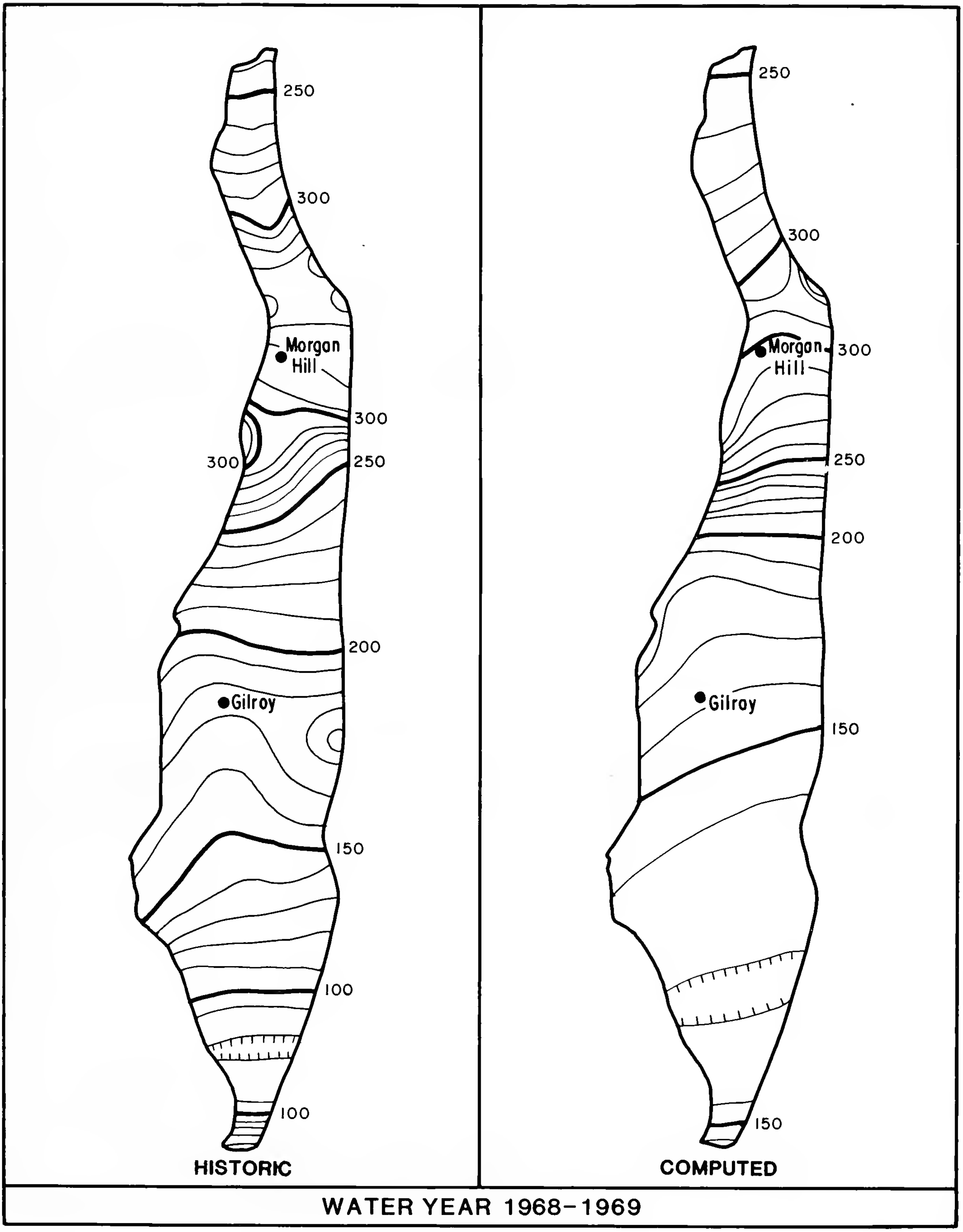
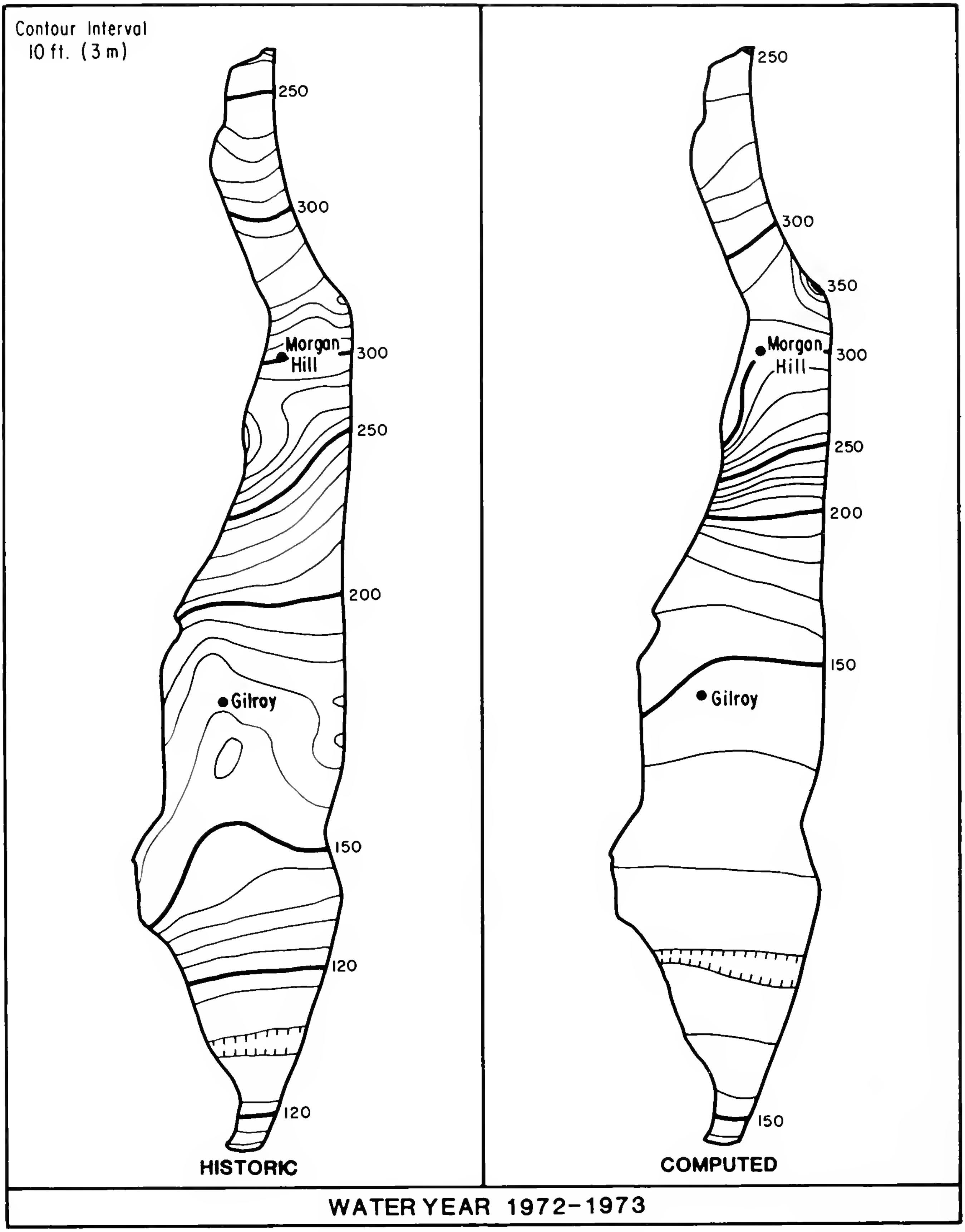


FIGURE 26.--Comparison of Historic and Model -



Generated Ground Water Elevation Contours.

CHAPTER V. GROUND WATER BASIN SURVEILLANCE SYSTEM

During the 1950s, surveillance of ground water in Santa Clara County was limited to that area north of San Martin and consisted of measuring depths to static and pumping ground water levels and analyzing the water being pumped. Because the intent of the program was only to monitor the water coming from the well, little attention was given to understanding the individual aquifer or group of aquifers that produced the water. Since that time, there has been an ever-increasing interest and concern about the ground water resources of Santa Clara County. More knowledge is needed about the physical conditions of the ground water resource -- how water infiltrates the ground water body, how and by what paths it moves from point to point within the ground water body, how it can become polluted or degraded, and what the effects of its extraction are.

Data required to monitor the ground water resource of South Santa Clara Valley include the following nine items:

1. Pumpage. Metered ground water pumpage by water year (October through September) is necessary to enable the accurate determination of an annual water balance; metered pumpage also is necessary to formulate operational plans, because the ground water resource is intensely used and responds rapidly to changes in pumping rates.

2. Unconfined Water Levels. Periodic ground water elevation data for selected locations in the unconfined ground water zone are necessary to accurately determine changes in storage. Most elevation determinations can be seasonal, but a few continuous recorders are necessary to identify periods of maximum stress of the ground water system.

3. Confined Water Levels. Elevation data of the confined potentiometric surface should be developed on a seasonal basis. These data are needed to provide information on pressure differences between the various aquifers and also to determine conditions of water supply.

4. Surface Inflow. A sufficient number of gaging stations along the perimeter of the ground water basin are required to form reliable estimates of tributary inflow.

5. Local Runoff. Tracts representing differing natural and developed areas should be instrumented with precipitation and flow instruments to determine contribution of valley areas to local runoff.

6. Artificial Recharge. Accurate inflow and outflow measurements for all percolation facilities, including both ponds and streams, are necessary to provide reliable data on the quantity of water deliberately recharged to the basin.

7. Surface Outflow. A sufficient number of gages on streams draining the valley are required to provide reliable estimates of quantities of surface water leaving the basin.

8. Transmissivity. A program of field testing selected water wells will provide accurate data on aquifer transmissivities.

9. Water Quality. Quality monitoring of surface and ground water is necessary to detect possible degradation before it proceeds beyond control. Quality data for surface water measuring stations, taken for a wide range of flows, will provide information on fluctuations of mineral constituents entering and leaving the basin. Similar data from monitoring wells will provide data on the mineral characteristics of the various parts of the aquifer system. The frequency of sampling and the analysis for specific mineral constituents will vary widely.

Water Level Measurements

A data gathering system that will provide information on the elevation of the upper surface of the unconfined ground water body must be based on adequate knowledge of: 1) the subsurface geology, 2) the subsurface hydrology, and 3) construction details of each monitoring well. The first two requirements have been met by the study reported on in this bulletin. An appraisal of the existing ground water level network was made in order to evaluate the third requirement. Wells measured for ground water levels between 1936 and 1978 were reviewed. Both a driller's log and construction details for each measurement well are necessary so that a relationship between water levels and aquifers can be developed. Of the 118 wells for which water-level data are available, only 17 have construction details available. Of the 101 remaining wells, 21 are of unknown depth.

A further requirement in the determination of the configuration of the unconfined ground water surface is that the monitoring wells should tap only those aquifers which do not have any significant degree of confinement. In general, wells in South Santa Clara Valley reaching depths greater than about 85 metres (280 ft) draw water from aquifers under some degree of confinement.

Table 16 lists all wells that were measured from the study period through 1978. Because of the general lack of adequate construction data for many of the wells measured, it is not possible to incorporate the majority of them into a meaningful water-level measurement network. Hence, a modified water-level measurement network should be implemented.

Table 16. Existing Ground Water Monitoring Network, South Santa Clara Valley

Well Location Number	Period of Record	Depth in Metres	Perforated Interval in Metres	Remarks
08S/02E-22D01	1936-78	26.2	---	No construction data
08S/02E-22F01	1968-78	74.7	---	No construction data
08S/02E-26M02	1947-77	45.7	---	No construction data
08S/02E-27G01	1968-78	7.9	---	No construction data
08S/02E-28H02	1968-78	---	---	Depth unknown
08S/02E-28H03	1974-77	9.1	---	No construction data
08S/02E-31Q01	1969-78	17.1	---	No construction data
08S/02E-34A01	1936-70	21.3	---	Destroyed
08S/02E-34E01	1968-75	---	---	Depth unknown
08S/02E-35G01	1937-78	45.7	---	No construction data
08S/02E-35M01	1959-78	27.4	---	No construction data
09S/02E-01C01	1938-78	45.7	---	No construction data
09S/02E-01E99	1936-39	33.5	---	Destroyed
09S/02E-01G98	1936-38	---	---	Destroyed
09S/02E-01J01	1937-77	41.1	---	No construction data
09S/02E-02C01	1937-78	83.8	---	No construction data
09S/02E-02G01	1939-78	68.6	---	No construction data
09S/02E-02J02	1948-78	34.7	---	No construction data
09S/02E-02P02	1972-78	C	C	Confidential log
09S/02E-02P99	1937-58	30.5	---	Destroyed
09S/02E-11C01	1958-78	36.6	---	No construction data
09S/02E-12B01	1937-78	54.9	---	No construction data
09S/02E-12E01	1937-78	65.5	---	No construction data
09S/02E-12F99	1937-46	36.6	---	No construction data
09S/03E-07H03	1968-77	91.4	---	No construction data
09S/03E-07L02	1953-78	60.4	---	No construction data
09S/03E-07L99	1937-53	60.4	---	Destroyed
09S/03E-08J02	1937-76	91.4	---	No construction data
09S/03E-15F01	1968-78	76.2	---	No construction data
09S/03E-15L01	1955-78	61.0	---	No construction data
09S/03E-16A01	1958-74	42.4	---	Destroyed
09S/03E-16C01	1936-78	91.7	---	No construction data
09S/03E-16J01	1948-78	121.9	---	No construction data
09S/03E-17C01	1968-78	---	---	Depth unknown
09S/03E-17K99	1936-57	54.9	---	Destroyed
09S/03E-18B01	1958-78	C	C	Confidential log
09S/03E-20E99	1948-54	85.7	---	Destroyed
09S/03E-20F01	1954-76	38.4	---	No construction data
09S/03E-20F99	1972-76	---	---	Depth unknown
09S/03E-20H01	1948-78	73.2	---	No construction data
09S/03E-21K01	1948-78	68.6	---	No construction data
09S/03E-22B03	1948-78	103.6	---	No construction data
09S/03E-22P99	1972-78	---	---	Depth unknown
09S/03E-23E01	1948-78	128.0	---	No construction data
09S/03E-25P01	1948-78	75.9	---	No construction data
09S/03E-26P01	1948-78	76.2	---	No construction data
09S/03E-27C01	1948-70	91.4	---	Destroyed
09S/03E-33G01	1948-56	50.6	---	Destroyed
09S/03E-33H01	1957-78	115.8	---	No construction data
09S/03E-33M03	1972-77	---	---	Depth unknown
09S/03E-34A99	1972-78	---	---	Depth unknown
09S/03E-34D01	1958-78	114.3	---	No construction data
09S/03E-34D99	1948-58	42.7	---	Destroyed
09S/03E-34M01	1975-78	---	---	Depth unknown
09S/03E-34Q01	1948-78	59.4	47-56	
09S/03E-35N01	1958-78	57.3	---	No construction data
09S/03E-35N80	1948-54	48.8	---	No construction data
09S/03E-35P99	1972-78	---	---	Depth unknown
09S/03E-36F01	1962-78	144.8	---	No construction data
09S/03E-36M01	1948-78	61.0	---	No construction data
10S/03E-01E02	1976-77	C	C	Confidential log
10S/03E-01N02	1969-78	40.2	---	No construction data
10S/03E-03C01	1948-78	67.1	---	No construction data
10S/03E-04G01	1948-69	51.8	---	Destroyed
10S/03E-05L02	1976-78	7.3	---	No construction data
10S/03E-11G01	1975-77	85.3	---	No construction data
10S/03E-13D03	1969-78	C	C	Confidential log
10S/03E-14D01	1972-78	61.0	---	No construction data
10S/03E-14R02	1968-71	27.4	---	Destroyed
10S/03E-23J02	1968-78	78.6	---	No construction data
10S/03E-24M01	1972-77	C	C	Confidential log
10S/03E-26J01	1975-77	C	C	Confidential log
10S/03E-36A05	1972-77	64.6	---	No construction data
10S/04E-06P01	1969-78	C	C	Confidential log
10S/04E-07E99	1973-78	48.8	---	No construction data
10S/04E-07F01	1969-74	79.2	---	No construction data
10S/04E-07F02	1974-78	---	---	Depth unknown
10S/04E-17F01	1975-77	55.2	---	No construction data
10S/04E-17K02	1969-78	76.2	---	No construction data
10S/04E-17N02	1969-78	---	---	Depth unknown
10S/04E-18G02	1975-77	56.1	---	No construction data
10S/04E-18J01	1975-77	C	C	Confidential log
10S/04E-18N99	1971-78	74.4	---	No construction data
10S/04E-20M01	1969-78	64.3	---	No construction data
10S/04E-21M01	1969-78	---	---	Depth unknown
10S/04E-30P05	1969-78	36.6	---	No construction data
10S/04E-31G04	1969-78	C	---	Confidential log
10S/04E-31R99	1971-78	---	---	Depth unknown
10S/04E-33M99	1971-76	---	---	Depth unknown
10S/04E-34E02	1969-78	---	---	Depth unknown
10S/04E-34L05	1975-77	49.7	---	No construction data
11S/04E-02D01	1969-78	86.9	16-85	
11S/04E-03J01	1972-78	126.5	---	No construction data
11S/04E-04C03	1969-78	---	---	Depth unknown
11S/04E-05D01	1969-70	---	---	Depth unknown
11S/04E-05L99	1971-78	---	---	Depth unknown
11S/04E-06B01	1969-78	213.7	20-210	
11S/04E-06D01	1969-78	143.3	33-140	
11S/04E-06H01	1969-78	105.5	30-105	
11S/04E-06N01	1968-76	82.9	---	Destroyed
11S/04E-06P02	1969-78	C	---	Confidential log
11S/04E-08K01	1969-78	91.4	---	No construction data
11S/04E-08K02	1975-77	---	---	Depth unknown
11S/04E-09K02	1975-77	41.5	---	No construction data
11S/04E-09P01	1975-77	---	---	Depth unknown
11S/04E-10D04	1969-78	112.8	---	No construction data
11S/04E-10K01	1971-77	109.7	---	No construction data
11S/04E-11C01	1969-78	131.1	---	No construction data
11S/04E-15J01	1969-78	136.6	121-136	
11S/04E-16J01	1971-75	53.3	---	No construction data
11S/04E-17C03	1969-71	---	---	Destroyed
11S/04E-17M01	1968-78	24.4	---	No construction data
11S/04E-21B02	1977	C	C	Confidential log
11S/04E-21P01	1969-78	---	---	Depth unknown
11S/04E-21Q01	1972-78	---	---	Depth unknown
11S/04E-22N03	1972-78	67.1	---	No construction data
11S/04E-27E02	1971-78	---	---	Depth unknown

C - Confidential well log; data are on file with the Department of Water Resources but not available for public release (Water Code Sec. 13752).

Well Qualification

The first step in selecting wells for a modified measurement network is determining what aquifer, or group of aquifers, the measurements of the well should represent; this step is called well qualification. A qualified well is defined as being one that meets all of the following criteria:

1. The well is accurately located. An essential factor because several wells may be grouped in a cluster and measurements may not always be for the same well.

2. A well log is available and on file with the agency performing monitoring operations. An electric log of the well, although not entirely necessary, is desirable.

3. Well construction data are available to the agency performing the monitoring operations.

4. A fairly long period of record of measurements is available. Although not as essential as the first three criteria, a historic water-level record is preferable to a new one.

Using the above data, personnel with an understanding of subsurface geology and ground water hydrology can determine that water-level measurements from a particular well reflect the potentiometric surface of a specific aquifer, or group of aquifers. Where this is done, fluctuations of the water levels in the particular well become meaningful data.

Qualified monitoring wells should be located with the aid of information on the buried stream channels, shown on Figures 5A through 5J, augmented by knowledge of lake-bottom clay deposits. Also, the ideal monitoring network will contain not only representative wells tapping principal aquifers, but additional wells reflecting effects of faults.

Proposed Network

The development of the proposed network of monitoring wells involved a detailed examination of the subsurface geology discussed in Chapter II. Monitoring well locations thus selected should reflect water levels for given zones.

Geohydrologic data reveal an essentially unconfined ground water zone in the northwest portion of the valley between Coyote and Madrone. Minor confinement occurs locally at depth due to the presence of discontinuous clay lenses. The thickness of valley fill materials increases southeasterly toward Hollister.

Between Morgan Hill and Gilroy, impermeable lacustrine clays divide the ground water into a shallow unconfined zone and a deeper confined zone. Confinement increases to the southeast,

where lacustrine clays separate the deeper confined aquifer into at least two zones in the Bolsa area.

Two types of monitoring wells are recommended. Shallow wells in the northwest and middle sections of the area will monitor depths of 85 m (280 ft) or less. Multiple wells will monitor both the shallow unconfined zone and deeper confined zones in the middle section of the area. Multiple wells in the southeastern section of the area will monitor both intermediate and deep confined aquifers, and should be about 200 m (650 ft) deep.

The recommended minimum network contains 20 shallow wells and 16 multiple-completion wells. Figure 27 shows the areal distribution of the proposed network and Table 17 presents location and monitoring interval data for the proposed monitoring wells.

The water-level monitoring network coincides with the proposed water quality monitoring network to minimize the number of wells to be monitored.

Implementation of Network

Several steps should be taken in establishing the modified monitoring network:

1. Search records and make a field canvass to locate all well data in the vicinity of proposed monitoring well locations.

2. Determine if an existing well can be used or modified for use as a monitoring well.

3. If Step 2 is negative, or if cost is excessive, drill a test hole and construct therein a single-completion or multiple-tube piezometer.

4. Locate monitoring wells beyond the area of interference of large municipal and industrial wells. Consideration also should be given to restricting the placement of new high-capacity wells that may adversely affect existing monitoring wells.

5. Keep the continuity of measurements in existing wells unbroken until there is some overlap of record with those of new or replacement facilities.

Many of the water-level measurements now available are taken by the agency that operates the well. Such measurements should be continued by such agencies for their own operating reasons.

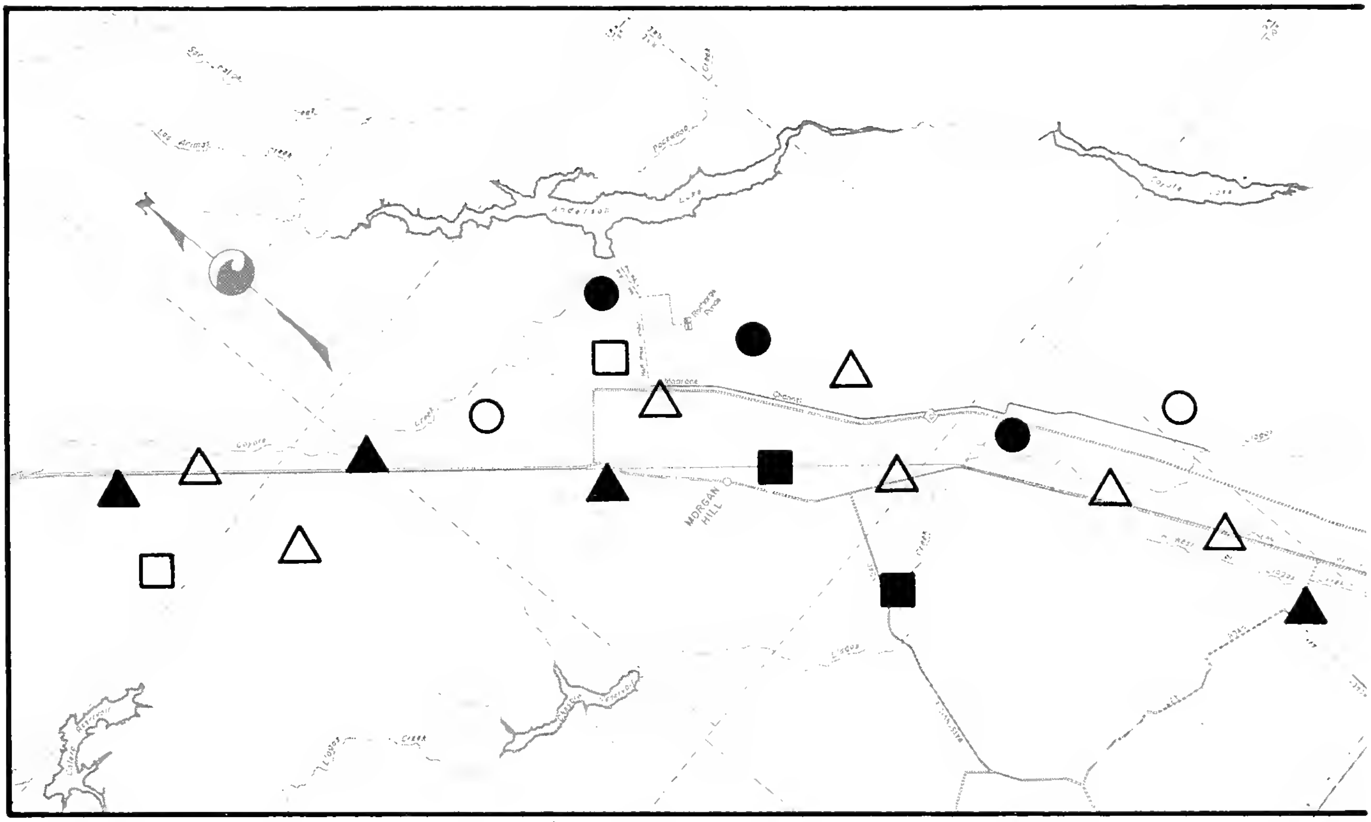
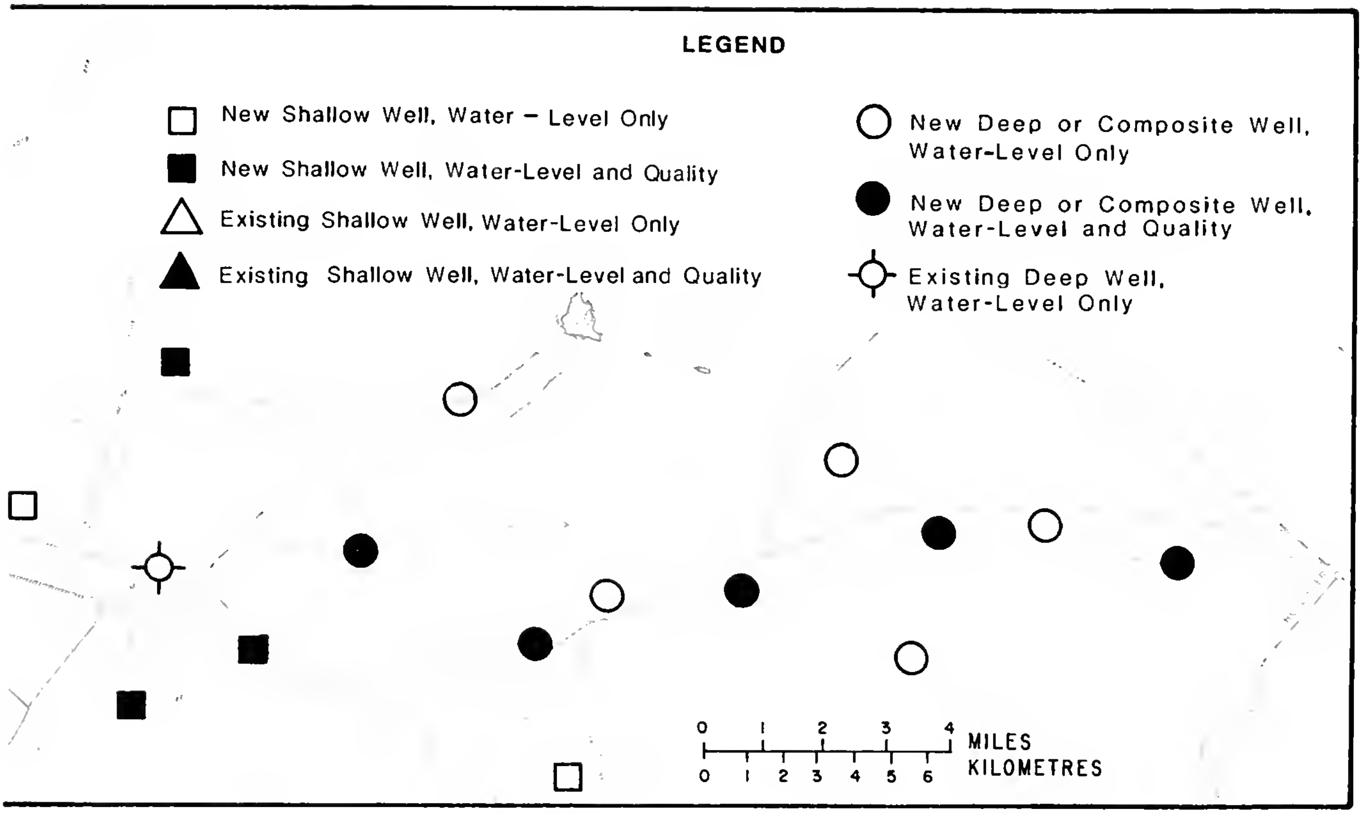


FIGURE 27.--Proposed Ground Water Monitoring



Network, South Santa Clara Valley.

Table 17. Proposed Ground Water Monitoring Network, South Santa Clara Valley

Location	Type*	Monitoring Interval (Approximate Depths) Feet	Metres	Existing Wells SCVWD	Type*	DWR	Type*	Water Level	Water Quality
08S/02E-27R	S	100-200	*30-61*	---	-	08S/02E-27R	S	x	x
08S/02E-35G	S	100-200	*30-61*	08S/02E-35G01	S	08S/02E-35H02	S	x	
08S/02E-34L	S	50-120	*15-37*	---	-	---	-	x	
09S/02E-01R	S	50-180	*15-55*	---	-	09S/02E-01R02	S	x	x
09S/02E-02Q	S	65-115	*20-35*	---	-	09S/02E-02Q04	S	x	
09S/03E-08M	M	100-165	*30-50*	---	-	---	-	x	
		215-265	*66-81*	---	-	---	-		
09S/03E-10N	M	100-150	*30-46*	---	-	---	-	x	x
		230-280	*70-85*	---	-	---	-		
09S/03E-16G	S	115-230	*35-70*	---	-	---		x	
09S/03E-20F	S	100-200	*30-61*	09S/03E-20F01	S	---		x	x
09S/03E-21B	S	100-200	*30-61*	---	-	09S/03E-21B01	S	x	
09S/03E-22J	M	100-150	*30-46*	---	-	---	-	x	x
		200-250	*61-76*	---	-	---	-		
09S/03E-26P	S	100-250	*30-76*	09S/03E-26P01	S	---	-	x	
09S/03E-28R	S	100-250	*30-76*	---	-	---	-	x	x
09S/03E-34Q	S	100-190	*30-58*	09S/03E-34Q01	S	---	-	x	
10S/03E-02J	M	100-150	*30-46*	---	-	10S/03E-02R03	S	x	x
		200-250	*61-76*	---	-	10S/03E-01E02	D		
10S/03E-04K	S	80-150	*24-46*	---	-	10S/03E-03D	S	x	x
10S/03E-12N	S	115-250	*35-76*	10S/03E-13D03	S	10S/03E-12N01	S	x	
10S/03E-24G	S	130-210	*40-64*	---	-	10S/03E-24G	S	x	
10S/03E-25L	S	100-210	*30-64*	---	-	10S/03E-25L02	S	x	x
10S/04E-18C	M	90-180	*27-55*	---	-	10S/04E-18C	S	x	
		220-300	*67-91*	---	-	---	-		
10S/04E-27N	S	80-260	*24-79*	---	-	10S/04E-27F	S	x	x
10S/04E-30J	S	80-260	*24-79*	10S/04E-30P05	S	---	-	x	
11S/03E-01R	S	80-200	*24-61*	---	-	11S/03E-02H01	S	x	x
11S/04E-05D	M	100-200	*30-61*	---		11S/04E-05D01	S	x	
		300-400	*91-122*	---	-	11S/04E-03G	D		
11S/04E-08M	S	100-250	*30-76*	---	-	11S/04E-08N	S	x	x
11S/04E-12N	M	180-230	*55-70*	---	-	---	-	x	x
		295-395	*90-120*	---	-	---	-		
11S/04E-16A	M	100-230	*30-70*	---	-	11S/03E-15A	D	x	x
		320-400	*98-122*	---	-	---	-		
11S/04E-26L	M	330-410	*101-125*	---	-	---	-	x	
		574-640	*175-195*	---	-	---			
11S/04E-27F	M	180-245	*55-75*	---	-	11S/04E-28A	S	x	x
		330-410	*101-125*	---	-	11S/04E-27D	D		
11S/04E-33L	S	131-295	*40-90*	---	-	---	-	x	
11S/04E-36P	M	250-350	*76-107*	---	-	---	-	x	x
		450-650	*137-199*	---	-	---	-		
11S/05E-32N	M	200-350	*61-107*	---	-	---	-	x	
		400-600	*122-183*	---	-	---	-		
12S/04E-12R	M	130-290	*40-88*	---	-	---	-	x	
		400-600	*122-183*	---	-	---	-		
12S/05E-08D	M	200-300	*61-91*	---	-	12S/05E-08D01	S	x	x
		400-600	*122-183*	---	-	---	-		
12S/05E-16D	M	200-300	*61-91*	---	-	---	-	x	
		400-600	*122-183*	---	-	---	-		
12S/05E-21J	M	200-300	*61-91*	---	-	---	-	x	x
		400-600	*122-183*	---	-	---	-		

*Type: S - Shallow well
D - Deep well
M - Multiple-completion well

Appendix A

BIBLIOGRAPHY OF

GEOLOGIC AND GROUND WATER REFERENCES

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APPENDIX A

BIBLIOGRAPHY OF GEOLOGIC AND GROUND WATER REFERENCES

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Appendix B

GLOSSARY OF SELECTED GEOLOGIC AND HYDROLOGIC TERMS

Appendix B

GLOSSARY OF SELECTED GEOLOGIC AND HYDROLOGIC TERMS 1/

A

Anticline. A fold, the core of which contains stratigraphically older rocks; it is convex upward. Cf. Syncline.

Aquifer. A body of geologic materials that is sufficiently saturated and permeable to conduct ground water and to yield economically significant quantities of ground water to wells.

Artesian. An adjective referring to ground water confined under some degree of hydrostatic pressure.

Artificial recharge. The act of deliberately placing water underground.

B

Basalt. A dark-colored, fine-grained igneous rock, commonly of extrusive origin (i.e., ejected onto the surface of the earth).

Basic intrusive rock. A group of dark-colored, crystalline igneous rocks having a relatively low silica content and emplaced at some depth below the surface of the earth.

Bedrock. A general term for solid rock that underlies soil or other unconsolidated, surficial material.

C

Cell. A discrete unit, or part of a ground water model; of polygonal shape and containing a node at its center.

Chert. A hard, extremely dense sedimentary rock consisting dominantly of silica; it is tough and may be variously colored. The term "flint" is essentially synonymous.

Clay. An earthy, extremely fine-grained sediment composed primarily of hydrous aluminum silicate minerals (i.e., montmorillonite, etc.); grain size is less than 0.005 mm.

Confined ground water. Ground water under pressure significantly greater than that of the atmosphere and whose upper surface is the bottom of a bed of distinctly lower permeability than the bed in which the water occurs. Cf. Unconfined ground water.

Conglomerate. A coarse-grained sedimentary rock composed of rounded fragments larger than 2 mm in diameter set in a fine-grained matrix of sand, silt, or natural cement.

Consumptive Use. The difference between the total quantity of water withdrawn from a basin and the quantity of water returned to the source. It includes water transpired from plants, evaporated from the soil, and diverted from one watershed to another.

Contact. The surface between two different types or ages of rocks.

Continental origin. Said of geologic materials deposited on a continental mass as opposed to those deposited in an oceanic environmnent. Cf. Marine origin.

Crystalline rock. A rock consisting wholly of crystals or fragments of crystals; e.g., an igneous rock.

D

Deep percolation. Precipitation or applied water moving downward below the root zone toward storage in the ground water body.

Diabase. An intrusive igneous rock whose main components are the minerals labradorite (a feldspar) and pyroxene.

Dip. The angle that a bed or a fault plane makes with the horizontal.

E

Evapotranspiration. The combined loss of water through transpiration of plants and evaporation from the soil.

Extrusive. Said of igneous rock that has been ejected onto the surface of the earth. Extrusive rocks include lava flows and volcanic ash. Cf. Intrusive.

1/ Principal reference: American Geological Institute, Glossary of Geology, 1977.

F

Fault contact. A contact between two different types or ages of rocks that is formed by a fault.

Feldspar. A group of abundant rock-forming minerals belonging to the aluminum silicate group. Feldspars are the most widespread mineral group and constitute 60 percent of the earth's crust. Orthoclase and plagioclase are two common feldspar minerals.

Fine-grained. (a) Said of a crystalline rock in which the individual minerals have an average diameter of less than 1 mm.; (b) Said of a soil in which silt or clay predominate.

Flushed zone. A zone of geologic materials deposited under a marine environment and now containing fresh water.

Fluvial. Produced by the action of a stream or river.

Formation. The basic rock unit in the local classification of rocks, consisting of a body of rock generally characterized by some degree of homogeneity or distinctive features. Formations are combined into groups and subdivided into members.

G

Geohydrology. A term referring to the hydrologic characteristics of subsurface waters. Often used interchangeably with hydrology. Synonym: Ground water geology.

Gravel. An unconsolidated, natural accumulation of rounded rock fragments, consisting predominantly of particles larger than 2 mm, such as boulders, pebbles, or cobbles; the unconsolidated equivalent to conglomerate.

Greenstone. A dark green, compact altered basic to ultrabasic rock owing its color to such minerals as chlorite and hornblende.

Ground water. (a) That part of the subsurface water that is in the zone of saturation; (b) Loosely, all subsurface water as distinct from surface water.

Ground water basin. A valley-like area underlain by permeable materials which are capable of furnishing a significant supply of potable ground water to wells.

Ground water basin management. The planned use of a ground water basin as to yield, storage space, transmission capability, and ground water in storage. It includes: (1) Protection of natural recharge and use of artificial recharge; (2) Planned variations in amount and location of pumping over time; (3) Use of ground water storage conjunctively with surface water; and (4) Protection and planned maintenance of ground water quality.

Ground water body. All ground water, whether unconfined or confined, contained within a ground water basin.

Ground water divide. A ridge in the water table or other potentiometric surface from which ground water moves away in both directions.

Ground water pumpage. The quantity of ground water pumped.

Ground water subbasin. A discrete unit of a ground water basin.

Gypsiferous shale. Shale containing significant quantities of gypsum, a hydrous calcium sulfate.

H

Head. (a) The pressure of a fluid on a given area, at a given point caused by the height of the fluid above the point; (b) The water-level elevation in a well, or elevation to which water of a flowing well will rise in a pipe extended high enough to stop the flow.

Hydrologic Balance. An accounting of the inflow to, outflow from, and storage in a hydrologic unit; the relationship between evaporation, precipitation, runoff, and the change in storage, expressed by the hydrologic equation; the hydrologic budget.

Hydrologic equation. The equation that balances the hydrologic budget; $P = E + R + S$, with P as precipitation, E as evapotranspiration, R as runoff, and S as change in ground water storage (whether a negative or positive).

I

Igneous. Said of a rock that solidified from molten material.

Impermeable. A condition of a geologic material that renders it incapable of transmitting significant quantities of water. Synonym: Impervious. Cf. Permeable.

Indurated. Said of a compact rock or soil hardened by the action of pressure, cementation, or heat.

Infiltration. The movement of surface water downward into a geologic material through its natural openings. Cf. Percolation.

Intrusive. An igneous rock solidified from molten material below the earth's surface. Cf. Extrusive.

Isohyet. A line connecting points of equal precipitation.

Isohyetal map. A map showing isohyet contours.

L

Lacustrine. Pertaining to, produced by, or formed in a lake environment.

Lens. A geologic deposit bounded by converging surfaces (at least one of which is curved), thick in the middle and thinning out toward the edges, resembling a convex lens.

Lenticular. Resembling a lens in shape, especially a double-convex lens.

Limb. The side of a geologic fold.

Lithic. Said of a medium-grained sedimentary rock containing abundant fragments of previously formed rocks.

M

Marine origin. Said of geologic materials deposited in an oceanic environment as opposed to those deposited in an onshore condition. Cf. Continental origin.

Melange. A heterogeneous chaotic mixture of rock materials; specifically a body of deformed rocks consisting of fine-grained material thoroughly mixed with angular blocks of dissimilar materials.

Member. A discrete portion of a formation distinguishable from adjacent parts of the formation by color, hardness, composition, or other features. A member may be subdivided into a number of beds.

Metamorphic rock. Any rock derived from preexisting rocks by mineralogical, chemical, and structural changes, essentially in the solid state, in response to marked changes in temperature, stress, and chemical environment while at depth.

Micaceous. Consisting of, containing, or pertaining to mica, a group of platy aluminum silicate minerals.

Mudstone. An indurated mud having the texture and composition, but lacking the lamination of shale; a blocky or massive, fine-grained sedimentary rock in which the proportions of clay and silt are approximately the same.

N

Node. The point within the cell of a mathematical model at which all conditions are assumed to occur; the geometric center of a cell.

O

Oceanic volcanic rocks. Extrusive igneous rocks formed in a marine environment, commonly of basaltic composition.

Orographic. (a) Pertaining to mountains; (b) Said of the precipitation that results when moisture-laden air encounters a mountain range.

P

Perched. Unconfined ground water separated from the main ground water body by an unsaturated zone.

Percolation. The flow of ground water through natural openings of a geologic material. Cf. Infiltration.

Permeable. A condition of a geologic material that renders it capable of transmitting a significant quantity of water without impairment of its structure. Synonym: Pervious; Cf. Impermeable.

Physiography. A description of the surface features of the earth; synonymous with physical geography and comparable to geomorphology.

Piezometer. A facility emplaced to measure and record changes in ground water levels.

Pillow basalt. An oceanic basalt characterized by discontinuous, close-fitting, pillow-shaped masses ranging in size from a few centimetres to a metre or more in diameter. Pillow structures are considered to be the result of under-water volcanic action.

Poorly sorted. Said of a sediment that is not sorted or that consists of particles of many sizes mixed together in an unsystematic manner so that no one size predominates. In engineering usage, equivalent to well-graded. Antonym: Well-sorted.

Potentiometric surface. An imaginary surface representing the static head of ground water and defined by the level to which water will rise in a well. The water table is a potentiometric surface. Synonym: Piezometric surface.

Precipitation. The discharge of water (as rain, snow, or hail) from the atmosphere upon the earth's surface. It is measured as a liquid regardless of the form in which it originally occurred; in a sense, it may be called rainfall.

Primary opening. The original openings (pores, fractures, etc.) created at the time that a particular geologic material was formed. Cf. Secondary opening.

Q

Quartz. Crystalline silica, an important rock-forming mineral. It is, next to feldspar, the commonest mineral. Forms the major portion of most sands and has widespread distribution in igneous, metamorphic, and sedimentary rocks.

R

Recharge. The processes involved in the absorption and addition of water to the ground water body.

Residual soil. A soil that has developed in place in the absence of any significant transport.

S

Sag pond. A small body of water occupying an enclosed depression formed where fault movement has impounded drainage.

Sand. (a) A rock fragment or particle in the range of 0.074 to 4.76 mm diameter, and being somewhat rounded by abrasion in the course of transport; (b) A loose aggregate of mineral or rock particles of sand size predominantly composed of quartz; also a mass of such material, such as a beach.

Secondary opening. An opening (pore, fracture, etc.) created in a geologic material some time after the material had been formed and caused by faulting, weathering, chemical solution, etc. Cf. Primary opening.

Seep. An area, generally small, where water percolates slowly to the land surface; the flow is generally less than that of a spring.

S cont.

Semiconfined. A condition of an aquifer, or group of aquifers, in which ground water movement is sufficiently restricted to cause slight differences in head between differing depth zones during periods of heavy pumping and no head differences during periods of little draft.

Sequence. A major informal rock group that is greater than a formation.

Serpentine. A rock consisting almost wholly of serpentine-group minerals; e.g., antigorite, chysotile, etc., and derived from the alteration of previously existing ferromagnesian minerals such as olivine and pyroxene. Synonym: Serpentinite.

Shale. A fine-grained, indurated sedimentary rock formed by consolidation of clay, silt, and mud, and characterized by finely stratified structure that is parallel to the bedding.

Shear. A surface along which differential movement has taken place.

Silica-carbonate rock. A rock type developed through the alteration of serpentine; it is very hard and is composed of such minerals as quartz, dolomite, opal, and chalcedony.

Silt. A particle in the size range between sand and clay, specifically between 0.005 and 0.075 mm.

Siltstone. An indurated silt having the texture and composition, but lacking the fine lamination of shale; a massive mudstone in which silt predominates over clay.

Soil moisture. Water, or moisture contained in the soil or root zone.

Spring. A place where water flows freely and naturally from a rock or the soil onto the land surface or into a body of water.

Stratigraphic thickness. The thickness of a geologic unit measured at right angles to the direction of extension of the unit; the thickness measured perpendicular to both the strike and dip of a unit.

Stream capture. The natural diversion of the headwaters of one stream into the channel of another stream having greater erosional activity and flowing at a lower level; diversion affected by a stream eroding headward at a rapid rate so as to tap and lead off the waters of another stream.

Strike. The direction that the bedding or a fault plane takes as it intersects the horizontal.

Stringer. A thin sedimentary bed.

Subsoil. The soil below the surface soil or topsoil.

Subsurface inflow. Ground water movement through the subsurface into a ground water basin.

Subsurface outflow. Ground water movement through the subsurface out of a ground water basin.

Syncline. A fold, the core of which contains stratigraphically younger rocks; it is concave upward. Cf. Anticline.

T

Transmissivity. The rate at which ground water is transmitted through a unit width of an aquifer or group of aquifers. This term replaces the former term "transmissibility".

Tuff. A compacted deposit of volcanic ash and dust that may contain up to 50 percent of other materials such as sand or clay. The term is not to be confused with tufa, a chemical sedimentary rock formed along certain lake shores.

U

Unconfined ground water. Ground water that has a free water table; i.e., water not confined under pressure beneath relatively impermeable materials. Cf. Confined ground water.

Unconformable. Said of strata that exhibit a substantial break or gap in the geologic record; i.e., a geologic unit that is directly overlain by another that is not the next in stratigraphic succession. A condition which results from a change that caused deposition to cease for a considerable span of time; it normally implies uplift and erosion with a loss of some of the previously formed geologic record.

Unconsolidated deposits. A sediment that is loosely arranged or unstratified, or whose particles are not cemented together.

Upland ground water terrain. An upland area underlain by water-yielding materials and located adjacent to a ground water basin and possessing a high degree of hydrologic continuity with the valley floor.

V

Valley floor. The central portion of a ground water basin; an area of low-to-negligible relief suitable for agricultural or urban development.

W

Water-bearing. The capability of a geologic material to yield supplies of ground water of potable quality adequate for most beneficial purposes.

Water quality. (a) The fitness of water for use; (b) Loosely, the chemical and biological characteristics of water.

Water table. That surface in a ground water body at which the water pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water.

Water year. October 1 to September 30.

Well construction. The physical characteristics of a water well; e.g., method of drilling well, depth and diameter of casing, depth and type of perforations, size and extent of filter envelope, length of well seal, etc.

Z

Zone of saturation. A subsurface zone in which all openings in the geologic materials are filled with water. Under most conditions, the upper surface of this zone is the water table.

CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0 03937	25 4
	centimetres (cm) for snow depth	inches (in)	0 3937	2 54
	metres (m)	feet (ft)	3 2808	0 3048
	kilometres (km)	miles (mi)	0 62139	1 6093
Area	square millimetres (mm^2)	square inches (in^2)	0 00155	645 16
	square metres (m^2)	square feet (ft^2)	10 764	0 092903
	hectares (ha)	acres (ac)	2 4710	0 40469
	square kilometres (km^2)	square miles (mi^2)	0 3861	2 590
Volume	litres (L)	gallons (gal)	0 26417	3 7854
	megalitres	million gallons (10^6 gal)	0 26417	3 7854
	cubic metres (m^3)	cubic feet (ft^3)	35 315	0 028317
	cubic metres (m^3)	cubic yards (yd^3)	1 308	0 76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0 8107	1 2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35 315	0 028317
	litres per minute (L/min)	gallons per minute (gal/min)	0 26417	3 7854
	litres per day (L/day)	gallons per day (gal/day)	0 26417	3 7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0 26417	3 7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0 8107	1 2335
Mass	kilograms (kg)	pounds (lb)	2 2046	0 45359
	megagrams (Mg)	tons (short, 2,000 lb)	1 1023	0 90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3 2808	0 3048
Power	kilowatts (kW)	horsepower (hp)	1 3405	0 746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0 14505	6 8948
	kilopascals (kPa)	feet head of water	0 33456	2 989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0 08052	12 419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1 0	1 0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1 0	1 0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1 8 × °C)+32	(°F−32)/1 8

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